THE GEOLOGY OF SOILS AND SUBSTRATA

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PLATE I.

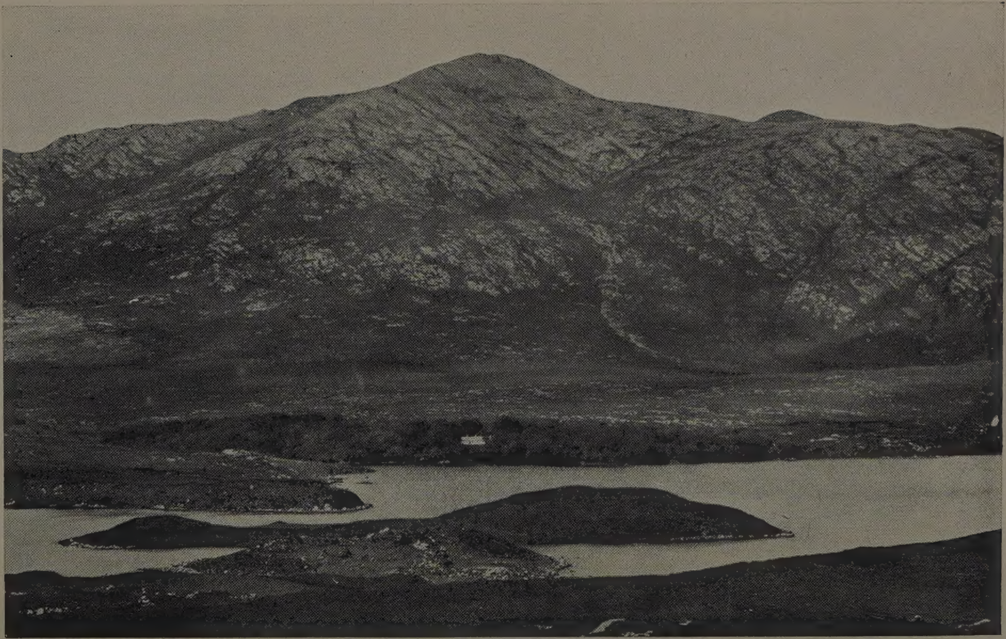

Photo by R. Welch.

LAND, FORMED OF METAMORPHIC SCHISTS, DENUDED OF SURFACE SOIL: DERRYCLARE LOUGH AND MOUNTAIN, EAST OF CLIFDEN, CONNEMARA.

Frontispiece.

ARNOLD'S GEOLOGICAL SERIES

THE GEOLOGY OF SOILS AND SUBSTRATA

WITH SPECIAL REFERENCE TO AGRICULTURE, ESTATES, AND SANITATION

BY

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PREFACE

THE object of the present volume on soils and substrata is to provide such information relating to the land-surface as will be useful to students and teachers of agriculture, to those occupied in the management of estates and farms, or in sanitary and engineering works, wherein it is important to consider the geological nature of different sites for residences and other purposes.

The subject is dealt with from a practical point of view. Under the term 'soils' are included the subsoils and surface soils, the term 'substrata' being, for the sake of convenience, applied to the igneous as well as to the various sedimentary and metamorphic formations, from which the mineral constituents of the soils are directly or indirectly derived. Prominence is therefore given to the chief mineral and lithological characters of the formations and to their economic products, little being said about their method of origin, and less about their life-history.

The great advances made and being made in the applications of science to agriculture, not only at the experimental stations at Rothamsted and elsewhere, but carried on in connection with special teaching at our Universities and the now associated agricultural colleges, as well as at many local schools, have tended to accentuate the practical importance of geology.

In endeavouring to illustrate the applications of this science over a comparatively wide field wherein it blends with diverse subjects, especially with chemistry, physics, and biology, the writer has naturally depended on others for information. It has been his aim to acknowledge as fully as possible in the text his indebtedness to various authorities, but he may be pardoned for here mentioning in particular the published works of the late Robert Warington, Mr. A. D. Hall (now one of the Development Commissioners), Mr. G. P. Merrill (of the United States National Museum), Dr. E. J. Russell (Director of the Rothamsted Experimental Station), and Dr. W. Somerville (Professor of Rural Economy at Oxford).

With regard to illustrations, permission was kindly granted by Mr. Godfrey Bingley, Dr. R. Kidston, and Professor S. H. Reynolds, for the reproduction of certain photographs in the British Association Collection; by the Council of the Geological Society for figures from papers by George Maw, Sir Joseph Prestwich, and Alfred Tylor; by the Council of the Geologists' Association, and by Dr. Henry Woodward (Editor of the *Geological Magazine*), for figures from reports and papers by the writer. The photograph of the Skye Croft was kindly contributed by Mr. A. E. Barnard.

HORACE B. WOODWARD.

CROYDON,
October, 1912.

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'A steep hillside is covered with a superficial sheet, a few feet in thickness, of gravel and soil resting upon the upturned edges of cleaved rocks or slates of Cambrian Age. The soil cap has moved downwards like a glacial sheet, the friction dragging back the edges of the underlying slates to a depth of several feet with a kind of shearing motion. The slates are disrupted at the joints, and those nearest the soil cap have been forced backwards and downwards into parallelism with it, and probably carried on for some distance. The rock slabs deeper down have been overturned, and those least affected have been merely disrupted, the effects of the surface-creep dying out altogether at a depth of less than 10 feet.'—*Note by Professor C. Lapworth, F.R.S.*

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THE GEOLOGY OF SOILS AND SUBSTRATA

CHAPTER I

INTRODUCTION

WHILE one object of geology is to trace out the development of life on the earth, the physical conditions which prevailed over different areas at successive periods, and the origin of the scenery, another great object, equally scientific, is to develop the practical applications of the knowledge in the matter of soils and subsoils, springs and water-supply, and in relation to economic products generally. Although agriculture is one of the oldest industries, and the practical experience transmitted, orally and otherwise, from one to another has been regarded by many a farmer as sufficient, yet during the past century some knowledge of geology has been advocated, and of late years its importance has been fully recognized by those who have devoted themselves to the scientific study of agriculture.

It has been argued by some that the soil is such an artificial product in cultivated areas that geology has little or nothing to do with it. To some extent only is this true. The primary constituents of the soil are derived from the superficial geological formations, and these formations or substrata, the weathered portions of which form the subsoil, have a direct bearing on the distribution of the soils and their fertility, on the value of an estate, and on the agricultural operations needed for successful cultivation.

More generally appreciated, perhaps, are the applications of geological knowledge to those sanitary questions which involve a knowledge of the strata at and below the surface, as in the matter of water-supply to villages and towns; the disposal of waste-water, sewage, and farmyard drainage; the situation of suitable places of residence; and the location of cemeteries.

From all these points of view, the nature of the subsoils, rather than of the surface soils, is of importance, and modern geological maps that represent in as much detail as possible their distribution are proving that geology can be of more and more service to engineers, architects, land agents, and agriculturists.

CHAPTER II

BRIEF OUTLINE OF GEOLOGY

The object of geology is to determine the structure and history of the earth from the various stony and earthy substances, the rocks and minerals, of which the land is formed. With the probable genesis of the earth, usually discussed under the heading of Cosmology, we are not here concerned. We have only to deal with the materials which appear at or near the surface—the granites and greenstones, the schists and slates, the clays, limestones, sands, sandstones and gravels, and other 'rocks,' as they are termed in geological language.

Geology teaches that the changes now taking place on the earth's surface, and in its stony crust, are the natural continuations of what has happened ever since great and small divisions of land and water were marked out and tenanted with forms of life.

The past changes, in fact, are illustrated by those now in action, as may be seen in the waste of land along the sea-coast, the formation of sandbanks and pebble beaches, and in the waste of hill and valley by rain, springs, rivers, and glaciers, whereby immense quantities of mud and coarser detritus, as well as mineral matter in solution, are borne along the valleys, the sedimentary matter in part lodged along the river courses, in part carried with the soluble matter to estuary and sea. Rain and springs, frost and wind, aid the processes of destruction along the sea-coast as well as inland. Thus, in time, great stratified formations are laid down, and with them are preserved many relics of the life of successive periods.

In the stony crust other prominent changes are taking place here and there, as evidenced by earthquakes and volcanoes; and in our granites and greenstones and other rocks, for the most part unstratified and of crystalline structure, we have evidence of former igneous activity. Some of the rocks, termed 'volcanic,' such as lava-flows and ashes, have been spread over the surface; other rocks, known as 'plutonic,' have been formed by the cooling of molten masses at a depth, after intrusion, among stratified or older igneous formations, and have been revealed at the surface by the subsequent erosion of overlying strata.

The intrusive and once deep-seated igneous masses have naturally baked or otherwise altered the rocks with which they came in contact, rendering them more or less 'metamorphic,' and this term is used to include the chemical and mineralogical changes caused by the pressure and heat of great earth movements. We therefore find examples both of contact and regional metamorphism.

There are thus three great groups of rock-formations:

1. Sedimentary, aqueous, and stratified.
2. Igneous.
3. Metamorphic.

The sedimentary rocks have been divided into a series of formations, according to relative order and age, as determined by superposition, and by the nature of the enclosed fossils. These organic remains approach more and more to the living types as we pass from the older to the newer strata.

The formations themselves are composed of the various kinds of materials now being accumulated on land, in river-valleys and lakes, or on the ocean floor: such as ooze and mud, clay, peat, sand, and gravel, together with the remains of calcareous, siliceous, and other organisms. Many of the formations have been depressed again and again beneath the level of ancient seas, and covered by great thicknesses of other deposits; so that, when upheaved and revealed by denudation, they have undergone considerable changes through pressure and the influence of underground waters, apart from the more local effects of igneous intrusions. Thereby in many cases sands have become sandstones or quartzites, muds and clays have become shales and slates, calcareous ooze and accumulations of shells and corals have become limestones, and minute siliceous organic remains, such as sponge spicules and radiolaria, have contributed to the formation of flint and chert.

Further, when brought to the surface, the rocks come directly under various agencies of decomposition and erosion, notably by the solvent action of carbonic acid in rain-water, by changes of temperature, wind, and the action of various burrowing animals. On such processes of weathering and disruption depend in the first instance the production of the surface soil and subsoil. Owing to the disturbances of the past, the many depressions, upheavals, and erosions, but few relics of old soils are preserved.

In the Coal Measures some of the underclays beneath coal-seams were evidently old soils and subsoils, as they contain roots of Lycopods known as *Stigmaria;* and upright trunks have been found occasionally in such abundance in some layers as to suggest a fossil forest. In the Purbeck Beds there are remnants of old soils at two or three horizons, but most prominently near the base of the series on Portland and near Lulworth. There the 'great dirt-bed' consists of carbonaceous clayey earth, with rounded fragments of limestone, and with overlying circular or oval masses of calcareo-siliceous matter (' Burrs ') from a foot or two to 9 feet across, with remains of silicified Cycads and Conifers.

In the latest Pliocene deposits of Norfolk, known as the Cromer Forest Bed Series, we find an estuarine division of clay, sand, and gravel, the upper part of which was subsequently weathered into a soil penetrated by small roots forming a Rootlet Bed, and covered here and there by hollows filled with peaty lacustrine deposits of freshwater origin.

At later periods we have evidence of submerged or submarine forests near the mouths of rivers, where muddy and peaty alluvial deposits, with stumps of trees, have undergone depression beneath the level of high tides.

Abroad, near Cairo in Egypt, and in Chalcedony Park, Arizona, there are remnants of 'petrified forests' in the shape of trunks or logs of silicified wood.

The names originally given to the geological formations were in some cases based on their lithological characters, or on other prominent features; some were provincial names; others were derived from the places where the strata were first studied. Thus we have the Old Red Sandstone, the Carboniferous or Mountain Limestone, the New Red Sandstone, Forest Marble, Cornbrash, Lower and Upper Greensand, Chalk, London Clay; the Lias, Gault, and Crag; the Wenlock Limestone, Portland Stone, and Bagshot Sand. Although these names have been rightly retained, it was soon realized that the formations represent physical conditions of restricted, though often wide, extent; that all were liable to lithological variations when followed across country, and some underwent changes so considerable that other subdivisions came to be introduced. The more persistent types were those of a clayey character, such as the Keuper Marls, the Lias Clays, the Oxford and Kimeridge Clays, the Gault and London Clay. The limestones, excepting the Chalk in this country, likewise the sands and sandstones, showed much more conspicuous changes, and as a rule were less persistent.

The Old Red Sandstone was found to consist, not only of red sandstones, but of marls and conglomerates, not invariably red in colour; and the same was the case with the New Red Sandstone. The Mountain Limestone, though forming mountainous scenery in parts of Ireland, the North of England, South Wales, and on the Mendip Hills, also occupied large areas of low land, notably in the central part of Ireland. The Lower Greensand was sometimes white or red, and included beds of siliceous limestone, clay, and fuller's earth, while the Upper Greensand was found to contain much chert, also pale calcareous sandstone, and yellow sands, as well as a good deal of green sand.

Thus some formations are more or less lenticular and local, others are widespread, and their thicknesses are subject to much variation.

The order of sequence was well established in course of time, and although this is maintained, yet sundry formations are locally absent, owing to deposition over a limited area, or to erosion prior to the deposition of the succeeding formation (see Fig. 42.) In certain cases, where great disturbances have taken place, the sequence has been inverted through folding and overthrusting, but in this country, at any rate, such disturbances do not often affect the agricultural lands.

It should be understood, then, that the term 'formation' is applied to a mass of igneous rocks or sedimentary strata that presents fairly uniform characters over a certain tract; or to strata that consist of alternating layers of different lithological character, as in the Lower Lias, the whole maintaining a general uniformity; or, again, to mixed strata, inconstant in extent and changeable in character, as in the cases of the Forest Marble, the Woolwich and Reading Beds, and the Glacial Drifts.

In subsequent chapters reference will be made to the relations between the principal formations and the form of the ground and scenery, and to the methods of representing the different strata on geological maps.

From the foregoing remarks it will be discerned that the country in which we live is the result of the long-continued operations of Nature, whose works are now progressing, if not with the same vigour and intensity as in past periods, yet under the same laws which have governed through an unbroken sequence of events and a vast period of time.

Nevertheless, the story told by British geology is no more identical with that of other regions of the earth's surface than is that of British history when compared with the history of other parts of the Old World, of America, or Australasia. The physical conditions and life in different areas have differed as they do now, though there were many widely-distributed organisms in the past, as in the present, that enable us to correlate the great geological divisions in different parts of the globe.

In dealing with the geology of Britain, it is a significant fact that the record of the rocks is more complete than that of any other area of similar extent, so that there is a great variety of rocks and geological formations, of subsoils and soils.

It must, however, be borne in mind that the same formations in different parts of England, as well as in other lands, are subject to change in lithological characters and thickness, and, in reference especially to agricultural geology, all must be considered according to local circumstances of climate, elevation, and the extent to which superficial deposits and wind-drifted material cover the more regularly constituted formations, and assist in producing a diversity of soils.

While the formations are representative of more or less local conditions, and each country must have its local stratigraphical divisions, the great geological systems mark the periods of time, and the chronological terms are thus used all the world over.

A Table of the geological Formations of Great Britain is given on the next two pages.

TABLE OF THE FORMATIONS OF GREAT BRITAIN.

SEDIMENTARY AND METAMORPHIC ROCKS.

		Systems.	Formations.		Thicknesses in Feet.
Cænozoic	Quaternary	Recent or Holocene	Alluvium with Peat, Blown Sand, Estuarine and Marine Beds: of Neolithic and later ages		up to 60
		Pleistocene	River Gravel and Brickearth, Raised Beaches: of Eolithic and Palæolithic ages		30
			Glacial Drift		200
	Tertiary	Pliocene	Cromer Forest Bed Series		30
			Norwich and Red Crags		up to 150
			Coralline Crag and Lenham Beds		40 to 80
		Oligocene	Hamstead Beds	Fluvio-marine Series	260
			Bembridge Beds		110
			Osborne Beds		100
			Headon Beds		190
		Eocene	Barton Sands Barton Clay	Upper Bagshot Beds	400
			Bracklesham Beds		400 to 650
			Lower Bagshot Beds		100 to 600
			London Clay		40 to 480
			Oldhaven and Blackheath Beds		10 to 60
			Woolwich and Reading Beds		15 to 150
			Thanet Beds		20 to 60
Secondary or Mesozoic		Cretaceous	Chalk		up to 1,750
			Upper Greensand	Selbornian	40 to 120
			Gault		100 to 300
			Lower Greensand		250 to 600
			Weald Clay Hastings Sands	Wealden	1,500
	Jurassic	Oolitic	Purbeck Beds		50 to 400
			Portland Beds		80 to 300
			Kimeridge Clay		100 to 1,200
			Corallian Beds		50 to 200
			Oxford Clay and Kellaways Beds		300 to 600
			Cornbrash		5 to 25
			Forest Marble, Bradford Clay, and Great Oolite Clay Great Oolite, Stonesfield Slate, and Fuller's Earth	Great Oolite Series	130 to 350
			Inferior Oolite Series, including Midford Sand (passage beds)		15 to 250
		Liassic	Upper Lias		25 to 200
			Middle Lias		50 to 350
			Lower Lias		450 to 960
	New Red Sandstone	Triassic	Rhætic Beds		30 to 120
			Red Marl and Sandstone (Keuper)		500 to 1,500
			Red Sandstone and Pebble Beds (Bunter)		220 to 2,000
		Permian	Magnesian Limestone Series and Marls Red Sandstone, Breccia, and Conglomerate		500 to 1,500

	Systems.	Formations.	Thicknesses in Feet.
Primary and Palæozoic	Carboniferous	Coal Measures	2,000 to 8,000
		Millstone Grit	up to 4,000
		Carboniferous Limestone Series and Calciferous Sandstone	800 to 4,000
	Old Red Sandstone and Devonian	Upper Old Red Sandstone	2,000 to 4,000
		Devonian	
		Lower Old Red Sandstone	
	Silurian	Ludlow Series	700 to 1,400
		Wenlock Series	2,000 to 4,000
		May Hill or Llandovery Series	2,000 to 3,000
	Ordovician	Bala and Caradoc Series	4,000 to 12,000
		Llandeilo Series	3,000 to 4,000
		Arenig Series	1,000 to 2,500
	Cambrian	Tremadoc Series	1,000
		Lingula Flag Series	4,000 to 5,000
		Menevian Series	600 to 750
		Harlech Series	3,000 to 8,000
Pre-Cambrian and Archæan	Torridonian	Torridon Sandstone and Longmyndian	—
	Uriconian	Wrekin Volcanic Series, Pebidian, etc.	—
	Dalradian	Highland Schists	—
	Lewisian	Hebridean or Fundamental Gneiss	—

IGNEOUS ROCKS.

Acid	Granite, Quartz-porphyry, Felsite, Pitchstone, Rhyolite.
Intermediate	Syenite, Diorite, Andesite, Trachyte.
Basic	Gabbro, Dolerite, Basalt (Greenstones).
Ultrabasic	Serpentine.

The Primary rocks would naturally include the Archæan and Palæozoic. Among Metamorphic rocks the most highly altered are the Archæan (Lewisian and Dalradian); but rocks of all later epochs have locally been subjected to metamorphic influences.

CHAPTER III

GEOLOGY AND PHYSICAL FEATURES

THE relations between geology and the character of the land surface are manifest in all regions.

The physical features are directly due to the character of the geological formations and their disposition; they are the results, in the first instance, of upheaval, but the present contours of mountain and hill are due mainly to the effects of erosion. As Suess has remarked: 'On the earth not an inch of the surface is known, the height of which has remained unaffected by denudation or other processes,' and quite recently Dr. F. W. Clarke has estimated that about 78,000,000 cubic miles of the primitive crust of the earth has been decomposed, forming a mass of rocks consisting of about 80 per cent. clays and shales, 15 per cent. sandstones, and 5 per cent. limestones.* These estimates, which are based upon the amount of soda lost by the decomposition of the igneous rocks, and the amounts retained respectively by the strata and the ocean, must be taken *cum grano*.

As the result of upheaval and erosion, it has come to pass that, as a rule, the older, and, for the most part, harder, rocks (Archæan and Palæozoic) form the more prominent features of mountain, fell, and high moorland, and they include the principal coal-mining and metalliferous districts. The Secondary or Mesozoic rocks form

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* *Nature*, May 30, 1912, p. 334.

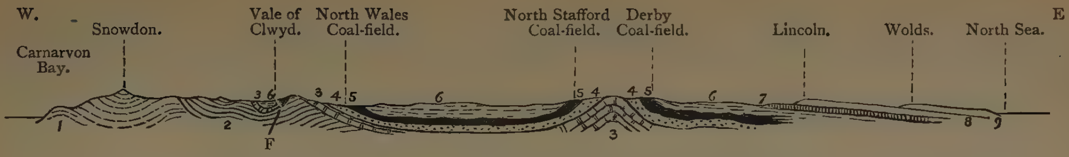

FIG. 1.—SECTION FROM NORTH WALES TO LINCOLNSHIRE.

3, Carboniferous Limestone Series.
2, Silurian.
1, Cambrian and Ordovician.

6, Permian and Trias.
5, Coal Measures.
4, Millstone Grit.
F, Fault.

9, Chalk.
8, Oolites.
7, Lias.

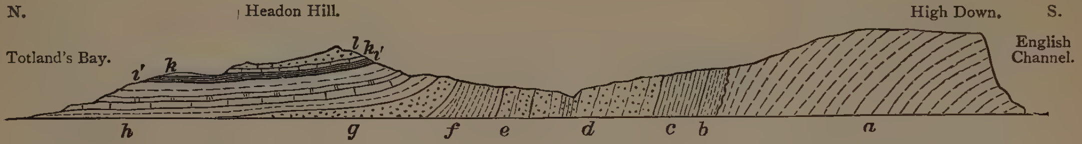

FIG. 2.—SECTION ACROSS HEADON HILL AND HIGH DOWN, ISLE OF WIGHT. (H. W. Bristow.)

l, Gravel and Sand.
k, Bembridge Beds.
i, Osborne Beds.

h, Headon Beds.
g, Barton Sands } Upper Bagshot Beds.
f, Barton Clay }

e, Bracklesham Beds.
d, Lower Bagshot Beds.
c, London Clay (Bognor Beds).

b, Reading Beds.
a, Chalk.

the alternating series of clay vales and stonebrash hills, together with the Chalk Downs, while the Tertiary, and most of the later deposits, constitute the lower undulating plains and river flats. The Secondary and newer strata thus form the chief arable, pasture, and meadow lands of England. This general succession is seen when we draw sections across the country from the Lake District to East Yorkshire, from North Wales to Lincolnshire or East Anglia (see Fig. 1), and from Cornwall and Devon to the shores of the Solent.

Formations of fairly uniform character, when rising into hilly ground, possess smooth outlines, as conspicuously seen in the Chalk Downs. This is the case also with clay hills, as in Primrose Hill, London, and sometimes with slaty rocks, as in Skiddaw; whereas other high grounds formed of hard and varied rocks, as in the Borrowdale Volcanic Series in Cumberland and Westmorland, give rise to features that are rough and rugged. Again, where bands of grit alternate with softer shales, as in the Millstone Grit formation, there we find crags of the harder rocks appearing along the crests and slopes of escarpments (see Figs. 40 and 42).

All rocks that are found at high elevations may also be found at low-levels, but the converse is not the case. Nevertheless, some of the bolder and more rugged features in Britain are formed of Tertiary volcanic rocks, the granite (or granophyre) of the Red Hills, and the gabbro of the Cuillin Hills in Skye. Vast earth movements, indeed, took place during the Tertiary period, especially in Miocene times, when many of the lofty mountain-chains of the world received great uplifts, and the Chalk and Eocene strata of the Isle of Wight were folded and tilted in places into a vertical position (see Fig. 2).

The limit of cultivation naturally varies according to elevation and latitude, or, in other words, to climatic conditions, and is, of course, also dependent on soil, subsoil, and drainage. The higher mountainous grounds are barren and rocky (see Plate I., frontispiece), but at any lower elevation there may be barren rocky, sandy, and boggy land that may be sterile, as in the case of Blown Sands, etc.

The older rocks and others of hard nature that have been elevated to very high positions are, for the most part, bleak and bare, with steep and unproductive slopes, where any soil is rapidly washed away. They form waste lands, except from a recreative or scientific point of view.

Deer forests in Scotland, and grouse moors there and elsewhere, occupy some of the higher mountain and moorland grounds where sufficient vegetation exists. In some tracts cotton-grass and bog-moss prevail, and the ground is peaty; somewhat lower heather abounds, and on the gentler mountain slopes there are heather and grass forming sheep-pasture, or the uncultivated grazing-grounds of the higher parts of Farmland. In the Northern Counties of England the limit of cultivation below the natural or hill pasture is about 1,000 feet, but the best wheat is not grown above an elevation of about 600 feet.

The upland cultivated areas among the older rocks are modified over considerable tracts by various Glacial Drifts, Boulder Clay, sand, and gravel, which occur on some of the fells and other moorland areas, as well as in the vales. Areas of woodland occur at various elevations, and on all formations, as will be subsequently noted.

The Secondary and Tertiary formations, which form the chief agricultural regions, usually rise to lesser elevations. The Liassic and Oolitic limestones and sandstones, the Chalk and other Cretaceous strata, form prominent uplands and bold escarpments, often too steep for the plough, as in East Yorkshire, Lincolnshire, the Midland and Southern Counties. Natural pasture-lands for sheep are found on the Oolitic uplands, as in the Cotteswold Hills and East Yorkshire, and on the Chalk Downs and Wolds. The limestones, sands, and sandstones along the dip-slopes, except on the more elevated Yorkshire moorlands, are largely under arable cultivation, with tracts of meadow, pasture, and woodland, and many heaths and commons on the sandy strata; while the alternating belts of thick clays form the great vales of the Midland and Southern Counties, mostly under grass as rich dairy, grazing, and meadow lands, famous fox-hunting grounds, with also many extensive woodlands, as well as arable lands and commons.

Among the Tertiary formations, the strata composed of clays, marls, loams, sands, and gravels, with occasional limestones, give rise to more mixed areas of arable and grass land, except in the case of the thick mass and extensive outcrop of the London Clay, which is mostly meadow and pasture land, with locally a good deal of woodland. The more sandy and gravelly strata are characterized by extensive heaths and commons on the uplands, but are mostly under cultivation in the valleys.

The same general remarks apply to the still newer Quaternary formations. The Glacial Drifts, however, instead of following the orderly succession of Palæozoic, Secondary, and Tertiary, already indicated (p. 14), extend irregularly and at various elevations over any of the Tertiary and older rock-formations. In the Eastern Counties, in particular, they almost wholly mask the Tertiary and Cretaceous strata. Their influence on the soil is therefore most potent. The Boulder Clay forms rich wheat land, and some of the calcareous loams of the Drift constitute the best soil in the country. The upland gravels and sands, where not under cultivation, form extensive heaths and commons. The great valley deposits of the larger rivers constitute some of the principal market-garden areas on gravel and loam, while the broad alluvial flats form, as a rule, rich meadow and pasture land, with also peaty grounds that are useful in supplying fuel, and marshy tracts, where osiers are cultivated.

An old agricultural writer remarked that Dorset might be divided into *Felix*, *Petræa*, and *Deserta*.* The fruitful vales are on the Lias, Oxford Clay, Kimeridge Clay, etc., where cider, cheese, and butter are made; the stony uplands comprise the Chalk and Upper Greensand (in part), Portland Beds, Cornbrash, Forest Marble, etc., where there is much land under arable cultivation; and the heaths, or so-called waste lands or deserts, are on the Upper Greensand, especially where covered by flint and chert detritus, and they include the large areas occupied by the Bagshot Sands and Clays.

All counties have their rich and comparatively poor lands. Some, like Kent, famed for fruit, have been termed 'garden' counties, or portions of counties have been described by enthusiastic writers as the Garden of Norfolk (the country around Aylsham), or the Garden of Edinburgh (that around Corstorphine). Again, some tracts have been termed 'golden valleys,' as the Golden Vale of the Dore in Herefordshire, Sapperton Valley, and the vale near Bitton in Gloucestershire.

The waste grounds in England and Wales are reckoned to amount to about 4¼ million acres, but some of these areas are capable of afforestation. The least productive counties in England and Wales, according to Topley, are Westmorland and Merioneth.

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* L. H. Ruegg, *Journ. Bath and West Eng. Soc.*, viii., p. 180.

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CHAPTER IV

GEOLOGICAL MAPS AND SOIL SURVEYS

Geological maps are intended to show the distribution at the surface, beneath the soil, of the various substrata or rock-formations; and the amount of detail which can be shown of course depends upon the scale.

The earlier maps of the Geological Survey were constructed on the Ordnance sheets of the scale of 1-inch to a mile. The more recent surveys have all been made on the 6-inch maps, some of which have been published, while others in the form of manuscript coloured copies have been deposited for public reference in the offices of the Geological Survey in London, Edinburgh, and Dublin.

On the 1-inch scale, geological maps of the whole of England, Wales, and Ireland, have been published, but much yet remains to be done in Central and Northern Scotland.

Commenced in Cornwall, Devon, and West Somerset, by De la Beche,* the areas then surveyed in England were free from those extensive deposits of Boulder Clay, Glacial Gravel, and Sand, which occur to the north of the Thames Valley. Consequently, when the survey was carried into those Drift-covered areas, it was found necessary to issue two series of maps, the one showing the so-called Solid formations and igneous rocks (sometimes termed collectively the bed rocks), with the Blown Sand, Alluvium, and sometimes the older valley gravels and brickearth; the other showing, in addition to the exposed areas of solid rocks, those occupied by the Glacial and Plateau Drifts (Boulder Clay, loam, gravel, and sand). The publication of the separate solid maps in mining areas was important, but elsewhere it was recognized in 1865 by Murchison that the solid maps alone did not really represent the geology, and it was necessary to have Drift maps in order to render the Geological Survey 'as valuable to agriculturists as it is to miners.' The Drifts, in some places 200 or more feet in thickness, powerfully influenced the scenery, agriculture, and water-supply, and were, in fact, as truly geological formations as the more regularly stratified rocks upon which they rested.

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* The first published geological survey maps were the 1-inch sheets of Devon, including parts of Cornwall and Somerset, issued in 1834 and 1835.

In short, it was admitted that geological maps which should adequately depict the structure of the country must show all the lithological subdivisions that could be represented. They must essentially be maps of formations, not of epochs or ages, and must indicate, where possible, the more or less lenticular masses of clay, limestone, and sandstone, that occur in many formations, though others of mixed and rapidly changing character might not be capable of subdivision.

On the 6-inch maps it has been possible to show many minor details which are of great importance, but which could not be represented on the 1-inch scale.

A few words may here be devoted to the nature of the evidence and work upon which rests the determination of the geology of a district or estate, whether by the expert or by the amateur.

To those fond of an open-air life, there can be few more congenial occupations than those of a geological surveyor. In England, the best times for field-work are in the spring or early summer and in the autumn, when the crops are not high or have been gathered in, and when the ditches are fairly free from vegetation, so that soil and subsoil can be observed or investigated with the aid of a spud.

In fixing the limits of the several formations, evidence is obtained from cliffs and scarps, from quarries, pits, mines, railway-cuttings, wells and borings, road-cuttings, excavations for new buildings, trenches for draining, etc. Large areas, of course, are grass-covered and wooded, and the geological evidence will be scanty, but here and there ant-hills, rabbit-burrows, ditches, saw-pits, may afford indications of the subsoil. The outbreak of a spring may locate the junction of clayey strata or of hard impervious rocks with overlying permeable strata, or it may prove the presence of a fissure in jointed or faulted rocks.

In ploughed fields the stones often indicate the nature of the subsoil, but their evidence has to be taken with caution, as noted (p. 76). Nevertheless, in some areas geological boundaries can be traced by evidence of the rock-fragments in arable lands. Thus, in numerous tracts bordering the Mendip Hills, both north and south, the Lower Lias or Blue Lias limestones, and the underlying Rhætic or White Lias limestones, are turned up by the plough, and by breaking the stones the limits of outcrop can be fixed within a few yards. The Cotham or Landscape Marble, which occurs at the base of the White Lias, is similarly ploughed up, and marks a definite horizon. In these cases we have distinct evidence of the direct relation between soil and subsoil. An abundance of pebbles or subangular stones of flint, quartz, etc., naturally indicates gravel, but it is often difficult to fix definite boundary-lines on the plateau-lands for these deposits, as towards the hill-margins the gravel may thin away to an irregular feather-edge, and there may be simply a gravelly soil on clay or other deposit, and partly incorporated with it. Definite gravel, 1 foot or more in thickness, should be mapped; in other cases gravelly soil might be noted on the map. All areas have been subject to erosion or denudation, so that the uppermost deposits are often very attenuated in places. Patches of Peat, Blown Sand, and Boulder Clay are sometimes scattered over wide areas, but in too limited extents to be shown on a geological map, and then the words 'peaty' or 'sandy,' or 'Boulder Clay' may be inserted on the map.

In correlating formations in different areas, the evidence of the included fossils is of the highest importance; this is the case also in disturbed areas, where formations of similar lithological character are displaced and brought together by faults, and again in the identification of samples of strata from wells and borings.

Fossils, however, are not always to be found; certain strata, especially sands and loams, are comparatively barren; and even in clays, like the London Clay, one may traverse many railway-cuttings and see not a single fossil. In some of these instances the fossils, originally present, have been dissolved out or otherwise obliterated by the chemical action of weathering processes. Thus, as pointed out by P. M. Duncan, the decomposition of pyrites in clays, like the London Clay, leads to the formation of sulphuric acid, which may unite with the calcic carbonate of fossil shells, and result in the formation of selenite. Ultimately, the selenite may be dissolved out, leaving sometimes moulds of its crystals; and this appears to have been the case in the exposed portions of the London Clay. The mineral is more abundantly preserved in the Kimeridge Clay. In many instances, however, the fossils of a formation are preserved in the soil.

Examples are seen here and there on the Great Oolite, as at Fairford, and on the Corallian at Steeple Ashton, where numerous corals have been gathered from the ploughed fields. On the Cornbrash, examples of *Pholadomya* and other bivalves are frequently found in the soil, while the Boulder Clay and some gravels also yield a mixture of fossils derived from various formations. Here, again, we see the direct relation between soil and subsoil.

The scope of the present work precludes any special attention being given to the fossils of various formations.*

Examples of clearly-marked geological boundaries may be observed on ploughed slopes of the escarpment of the Polden Hills, and on isolated hills or outliers near Wells, in Somerset, where the grey and green marls at the base of the Rhætic Beds rest on the red and variegated Keuper Marls. The plane of division is indicated by a fairly definite colour-line, less marked, of course, than where the strata have been freshly exposed in excavations.

On Chalk scarps, the whiteness of the ground in ploughed areas indicates that but little soil has there been preserved.

Among the more definite geological boundary-lines are those that can be traced in the Carboniferous limestones, grits, and shales; as, for example, among the dales of West Yorkshire and Durham, where the harder rocks form scars and crags that jut out beyond the softer shales. Again, in the Oolitic rocks of the Cotteswold Hills, and along the base of the Chalk Downs, where there occur in downward succession Upper Greensand and Gault, the geological boundaries may readily be traced.

The less definite boundaries are met with among the softer strata of sand, clay, and gravel, where there are no hard persistent rock-bands, as in the subdivisions of the Hastings Beds in the Wealden area, in many areas of Eocene strata, and notably in the case of the Glacial Drifts.

Some formations are, as a rule, very definitely marked off by abrupt changes in lithological character, as where the Oxford Clay rests on the Cornbrash in the Midland and Southern Counties of England. Between other formations there is a gradual passage, as where the Oxford Clay passes upwards into the sand of the Corallian, or the Kimeridge Clay merges into Portland Sands.

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* Figures of characteristic British fossils are given in Stanford's 'Geological Atlas of Great Britain and Ireland.'

Again, there may be an alternation of sediments or passage-beds of sands, loams, and clays, as between the Bagshot Beds and the London Clay. Fream remarked on the general fertility of lands along the junctions of different formations, owing to the admixture of soils.

It is interesting to know that in the latter part of the seventeenth century suggestions were made for maps of the soils and minerals of England. John Aubrey, whose 'Natural History of Wiltshire' was written between the years 1656 and 1691, remarked: 'I have oftentimes wished for a mappe of England coloured according to the colours of the earth; with markes of the fossiles and minerals.'* About the same time, 1684, Martin Lister suggested 'that *a soile or mineral map*, as I may call it, were devised.'†

The first fairly large geological map of England and Wales, issued in fifteen sheets on a scale of an inch to five miles, was that of William Smith, published in 1815. Smith, known as 'the Father of English Geology,' was eminent for the manner in which he combined practice with science, and in 1819 he commenced to issue 'A New Geological Atlas of England and Wales, on which are delineated, by Colours, the Courses and Width of the Strata which occasion the varieties of soil; calculated to elucidate the Agriculture of each County, and to show the Situation of the best Materials for Building, Making of Roads, the Constructing of Canals, and pointing out those Places where Coal and other valuable Materials are likely

* Edition by John Britton, 1847, p. 10.

† *Phil. Trans.*, xiv., p. 739.

to be found.'* Manuscript copies of William Smith's earliest geological maps were exhibited at agricultural meetings as early as 1803, and they were brought under the notice of the old Board of Agriculture in 1804.

The Agricultural Reports issued by the Board of Agriculture (1794-1813) contain much of geological interest, and some of the maps, such as that of 'The Soil of Norfolk,' prepared by Arthur Young, though in reality a Drift map, gave a good general idea of the distribution of the principal types of soil.†

In 1799 a British Mineralogical Society was formed mainly by chemists and mineralogists, and they gave public notice, in 1801, that they would examine, 'free of expense, all specimens of earths or soils, with a view of determining the nature and proportion of their different contents, with as much accuracy as shall seem requisite.' The Geological Society was established in 1807 by members of the Mineralogical Society and others, and one of the founders, G. B. Greenough, published a Geological Map of England in 1820 (dated 1819), on which some of the so-called Diluvial (Drift) Beds were shown in the Eastern Counties. The map was on the same scale as that of William Smith, and to a considerable extent based upon it.‡

In 1828 William Smith made a geological map of the Hackness estate for Sir J. V. B. Johnstone, who stated§ that 'The result thus obtained clearly demonstrated that the value of each field . . . corresponded to the variations of the strata; thus showing that . . . the geological character of a country, when accurately understood, pointed out at once the natural value of the land, and the system of cultivation best adapted to it.' It may be added that this map included the Drift or Diluvial deposits, and Smith observed that, 'If agricultural chemistry be ever successfully applied to the practical purposes of agriculture, it must be by proceeding with the chemical analysis of soils along the range of each stratum,' a view supported in a recently published volume by Mr. A. D. Hall and Dr. E. J. Russell (see p. 29).

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* Twenty-one English county maps were thus published (1819-1824).

† 'Agriculture of Norfolk,' 1804. It is important to know that the 'large paper' or quarto copies of the Reports were not actually published, but were circulated for corrections to be embodied in the final octavo Reports. See 'History of the Board of Agriculture,' by Sir Ernest Clarke, 1898, p. 17.

‡ H. B. W., 'History of the Geological Society of London,' 1907, pp. 7-9, 57, 58.

§ 'On the Application of Geology to Agriculture,' *Journ. Roy. Agric. Soc.*, 1840, i., p. 271.

The help that might be given to agriculture was realized by the Ordnance Survey in Ireland. The formation of a Geological Department was commenced in 1833 by J. E. Portlock, and in 1837 a soil laboratory was established by him at Belfast. He subsequently published a table of analyses of certain soils in Londonderry to show the soluble and insoluble matter, and the physical qualities of the soils. He remarked that, 'In looking at this table, the general character of the soil might, from the columns of water, organic matter, sand and gravel, and fine insoluble matter, be predicted with tolerable precision; the water and organic matter show the absorbing quality, the sand and gravel the loose or open character, the fine insoluble matter the close or clayey.' Finally, he pointed out that 'the physical condition, resulting from the combination of the more prominent constituents of the soils, is, in reality, the principal modifying cause of their fertility'* (see p. 103).

Later on, the published 1-inch maps of the Geological

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* 'Report on the Geology of Londonderry, and of parts of Tyrone and Fermanagh,' 1843, pp. 688, 689. The official geological work was placed in 1844 under the Office of Woods and Forests, and the Geological Survey in Ireland then commenced a more independent existence.

Survey of Ireland, although coloured to show the solid geology, were stippled over the Drift-covered areas. More detailed Drift surveys on the 6-inch maps of the country around Dublin, Belfast, Cork, Limerick, and Londonderry, have since been published on 1-inch maps.

In his address to the Geological Society in 1840, Buckland referred to the proposed establishment of a Museum of Œconomic Geology, since called the Museum of Practical Geology. He mentioned that Richard Phillips, the distinguished analytical chemist, would conduct analyses of soils, etc. The museum was to contain 'specimens of soils, subsoils, and of the rocks from the decomposition of which they have been produced.' Proprietors of land were to be solicited 'to contribute from their estates labelled examples of soils, with their respective subsoils; and all persons who wish for an analysis of any sterile soil, for the purpose of giving it fertility by the artificial addition of ingredients with which Nature had not supplied it, may here obtain, at a moderate cost, an exact knowledge of its composition, which may point out the corrective additions which it requires.' Little, if anything, however, appears to have been done to carry out this undertaking.

Buckland also referred to the appointment in July, 1839, of a Geological Committee by the English (afterwards Royal) Agricultural Society, as an indication that landed proprietors and cultivators of the soil had some faith in 'the important services' which a knowledge of geology might render 'to the improvement of the productive capabilities of the land.' It was, indeed, the opinion of the Committee that 'many facts might be adduced in support of the connection between the geological and agricultural characters of different districts.'*

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* *Proc. Geol. Soc.*, iii., pp. 212-216; and *Journ. Roy. Agric. Soc.*, 1840, i., p. li.

In connection with this subject, Philip Pusey observed that 'Great assistance may doubtless be derived from the knowledge which geological maps have lately afforded us as to the general outlines of the various subsoils which lie immediately under the surface of our fields, and powerfully affect, as every practical farmer knows, the produce of the upper soil, through which alone the *plough usually* passes.'*

The geological surveyor is accustomed to hear quaint remarks about his proceedings from the less educated farmer who occupies a small holding. When engaged on the Drift survey on the Chalk uplands in Buckinghamshire, a sturdy tiller of the soil came up to the writer to demand his business, and when it was explained that the object was to make a map of the soils and subsoils, the farmer exclaimed: 'What do you know about soils and subsoils? Tell me, now, which is the best land about here?' The land was formed of Chalk, exposed mainly on the slopes, with coverings of clay-with-flints, gravel, and brickearth on the uplands. It was easy to point to the tracts of brickearth as affording the best soils, whereby the farmer's attitude of apparent contempt was modified, and he went away, exclaiming: 'Well, well, Gover'ment be all'ays a doin' summut queer.'

There still remain in Great Britain large areas where the Drift deposits have not yet been mapped—in the Midland and Western Counties, in Central and North Wales, and in Scotland—and it is not surprising that practical farmers and agricultural writers have differed with respect to the advantages of geological knowledge, when we look at some of the maps that were intended to illustrate the variation of soils, in the reports published by the Royal Agricultural and other Societies. Many of these little maps show only the solid geology in areas where the soils are far more largely influenced by Drift deposits.

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* *Journ. Roy. Agric. Soc.*, 1840, i., p. 1.

Thus, David Low observed 'that the relations which we can trace between the mineral deposits of a country and the character of the soil are often uncertain and obscure . . . that, within the limits of the same geological formation, soils are greatly varied, and that the mere knowledge of the formation will not enable us to predicate the character of the soil of any given tract, either with respect to its texture, its composition, or its productiveness.'* As S. V. Wood, jun., pointed out in 1865, in reference to the Eastern and Midland areas, the observer was 'often baffled by the highly fictitious representation given in every geological map.'

During recent years, the advantage of a knowledge of geology to the agriculturist, and the value of detailed 6-inch maps of both Solid and Drift formations, has been amply acknowledged by Mr. Primrose McConnell, at one time tenant farmer of Ongar in Essex, by Professor Douglas A. Gilchrist, and others.

Especially valuable is the statement made by Mr. A. D. Hall and Dr. E. J. Russell in their 'Report on the Agriculture and Soils of Kent, Surrey, and Sussex' (1911).† In a previous report (1902) by Mr. Hall and Mr. F. J. Plymen, it was remarked that 'the geological map of the country furnishes the only possible basis for a classification and survey of its soils—at any rate, as far as the preliminary work goes.' In the later work, Mr. Hall observes (p. iv): 'It will be seen that we have taken the geological formations as the basis of our work, and have assumed that each formation represented in the district will give rise to a soil type which can be characterized both by its mechanical analysis and by special features in the farming which prevails over its outcrop. The justification for these cardinal assumptions was obtained in the early stages of the work by following the dividing-line representing the outcrop of two formations, and finding (1) that the dividing-line held for the soils as well as for the underlying formations; (2) that the soils from any formation (with one or two exceptions) did show on analysis certain common features which marked them off from other soils. These conclusions have been strengthened as our work proceeded. All our experience in the field goes to show that each formation in the area under consideration gives rise to a distinct soil type, the characteristic composition of which can further be recognized by making up an average from the mechanical analyses of the samples taken from that formation.'

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* 'Elements of Practical Agriculture,' 4th edit., 1843, p. 43.

† Published by the Board of Agriculture, price 2s. 6d.

Allowances, of course, have to be made in all cases for wind-drifted or other adventitious material in the soil, and for down-wash on slopes. The above quotation, however, shows the importance of a careful, detailed geological (or subsoil) survey, and demonstrates how in certain cases, when the strata are fairly flat, and belts of different formations occur in succession, the soils may vary in a general way according to contours.

Similar results were notified in 1906, in the Vale of Belvoir and bordering tracts, by Mr. G. W. Lamplugh,* who had the advantage of some discussion on the ground with Mr. Hall and Professor T. H. Middleton. There it was found that 'The geological boundaries conform fairly well to the varied character of the soils and subsoils, though the margins of the superficial deposits are rarely so sharply defined as the lines necessarily drawn for their delimitation on the map might seem to imply.' *

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* 'Geology of the Melton Mowbray District,' etc., *Mem. Geol. Survey*, 1909, p. 99.

SOIL AND SUBSOIL MAPS.

Here it must be remarked that a map of the surface soils alone would give a very imperfect idea of the capabilities of the land; it would fail to indicate the geological structure, and the pervious or impervious nature of the subsoils. Moreover, as soils change laterally at irregular intervals without any surface indications in grass-covered fields or woodlands, it would be far more difficult to draw any definite geological lines to separate the varieties of soil than it is to draw lines of approximate division between exposed areas of different subsoils which, whether in uniform or varying masses, overlie one another.

No actual map showing the distribution in detail of the surface soils over any extended area has yet been published, so far as the writer is aware. The so-called soil maps of the United States, Germany, etc., are in reality subsoil maps, with indications of the nature and depth of the soil at particular spots; but they do not show the superficial extent or boundaries of the minor lithological variations in the soils. Nevertheless, wherever the general type of soil closely corresponds with that of the subsoil or substratum, and both are fairly uniform over large areas, which is the case, for example, in North-Western Wisconsin, as shown by the 'Soil Survey' under Mr. S. Weidman, the maps, though admittedly not showing details, must be valuable guides to those taking up fairly large tracts of land. As he says, 'It is important to know the character of the soil to a depth of 3 or 4 feet below the surface,' the surface soil being previously stated to extend to depths of 6 to 8 inches.*

When we learn that in 1905 more than 20,000 square miles were surveyed in the United States, with the aid of forty-five assistants in soil survey, at an average cost of rather less than 9s. per square mile (not including travelling expenses), it will be understood that detailed variations, even in the prevailing subsoils, could not be mapped. De Lapparent has rightly observed that the best Agronomic map was still a geological map of the subsoils on a large scale.*

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* Bulletin No. xxiii., *Wisconsin Geol. Survey*, 1911, p. 35.

Joshua Trimmer, who was engaged on the Geological Survey for a few years, published, in 1850, 'Proposals for a Geological Survey, specially directed to Agricultural Objects.' The object was to show—

> 1. Those superficial deposits which are omitted from ordinary geological maps, but which are, obviously, of the most importance to the agriculturist.
> 2. The variations in the mineral character of the real substrata—the supposed surface—of our present geological maps in greater detail.

It will be seen that these two objects are carried out in the modern Drift maps of the Geological Survey, especially those on the 6-inch scale, where details of the 'real substrata' or solid rocks are shown.

The illustrative map given by Trimmer was essentially a Drift map, with details, however, of the variations of soil in the Alluvial deposits. He divided soils into—(1) Local, (2) Alluvial, and (3) Erratic.† The 'Erratic Soils' were, however, the Drift-formations—in reality, subsoils from which some of the Local Soils were directly derived.

The most important feature in his map was the introduction of symbols to indicate the depth of soil and subsoil at particular spots. The symbols were not, on the whole, well chosen, excepting those for the subsoil, which include *gr.*, gravel; *s.*, sand; *cl.*, clay; *gs.*, gravel mixed with sand; *m.*, marl, etc. Letters having no reference as a rule to the words indicating the different soils were chosen. It would be better to adopt capitals for the subsoils (including Drifts), and others for the soils; thus, $\frac{\text{sl } 8''}{\text{GS } 10'+}$ would indicate 8 inches of sandy loam over 10 feet (base not seen) of Gravel and Sand. The general system of nomenclature thus suggested by Trimmer has been widely adopted. (See p. 78.)

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* *Traité de Géologie*, 5th edit., 1906, p. 24; and H. B. W., review in *Geol. Mag.*, 1908, p. 277.

† This comprehensive grouping coincides generally with that to which Mr. G. P. Merrill has applied the name *Regolith*, meaning the 'earthy mantle' of soil and subsoil, as well as the various unconsolidated superficial Drift gravels, etc.

The depth of soils and nature of subsoils are ascertained—(1) By direct observation in natural and artificial excavations; (2) by means of a spade usually sufficient for a depth of 2 feet; (3) by light hand-borer where many borings are required and time is important; and (4) by heavier hand-boring implements where greater depths up to 6 feet or more are desirable.

Heavier boring tools are required for determining the geological structure, in obscure areas, at depths of more than 6 feet—with auger for sands, clays, and loose materials; punch for gravel and soft rocks; and chisel or jumper for hard rocks.

Notes should be made of the nature of the subsoil, whether much weathered, fissured, or disintegrated into rubble, or fairly unaltered, as is often the case with the Chalk. The depth of brown or weathered blue clay should be noted, and if it becomes shale at a depth; also of decalcified gravel, Boulder Clay, or other more or less residual accumulation.

Both soil and subsoil should be tested to ascertain if they are calcareous, or contain limestone pebbles. The level of ground-water, if present, should be recorded. In some areas where igneous rocks are irregularly decomposed, as among the granitic rocks of Jersey, it would be difficult in many places to map the areas of decomposed rocks from those that remain solid.

For records of soils on maps, it is necessary to have the precise information at particular spots; for general purposes of ascertaining the soil characteristics of a field, samples are taken from different parts and averaged. (See p. 35.)

On the Rothamsted Estate, near Harpenden Station, Hertfordshire, the subsoil is Chalk irregularly piped, and covered with the so-called Clay-with-flints. This latter formation comprises not only the true Clay-with-flints (see p. 223), but a mixed assemblage of mottled clay, loam, sands, and pebble gravel, relics of Reading Beds, disturbed and redeposited probably during the Glacial period, as there are also remnants of Drift gravel. Thus, in the area there is nearly every variety of sedimentary deposit. The piped Chalk comes here and there in irregular pinnacles to about 8 feet from the surface, lined with dark brown Clay-with-flints blackened by manganese oxide. This accumulation, with also red and mottled clay more or less stony, forms the main subsoil, having a mixed, heavy, and somewhat stony soil. On this ground the arable fields are situated. On the grass-land the soil is loamy, with few stones. On the slopes bordering the valleys the soil is also lighter, but mixed and more or less stony, while directly on the Chalk slopes there is a downwash of light, loamy, and gravelly soil.

With the exceedingly mixed condition of the subsoils, as seen in adjacent pits, it is most probable that here and there on the heavier ground the Chalk, with pipes or pockets of sand and gravel, approaches the surface, and acts as dumb-wells to take away some of the rain-water. Nevertheless, the soil does not vary sufficiently in character on the heavy upland area to indicate the precise positions of any underlying pockets of sand and gravel.

Judging from the geological evidence, the conclusion would be that the plateau-ground occupied by the Clay-with-flints, etc., must be treated from one general point of view, based on the fact that the subsoil is for the most part heavy. The results of analyses here and there of lighter portions of the soil or subsoils would hardly throw light on the general agricultural capabilities of the fields, which would be more affected by aspect and shelter than by other physical conditions. If analyses be made from the mixture, say, of a dozen samples of soil taken from different parts of one field, the best indication of its agricultural value, from a chemical and mechanical point of view, would then be obtained.

These observations were made by the writer in 1903, when he was deputed by the Geological Survey to visit the Experimental Farm at Rothamsted, and, while noting the relations of soils and subsoils, to make a map of the principal types of soil.* It was satisfactory to learn from Mr. A. D. Hall, in the following year, that the results of recent mechanical analyses of the Rothamsted soils, taken from the different experimental fields, show that 'Complex as the Rothamsted subsoil certainly is, it is not too much to say that a single analysis from any part of the land would show the type of soil to be dealt with over the whole area.' † (See also p. 107.)

From the foregoing remarks, it will be gathered that a good subsoil map which shows the variations in the strata, whether Drifts or the more regularly stratified formations, will always indicate the general distribution of the surface soils, and must be of the highest importance in appraising the value of an estate. The 1-inch geological map can only be regarded as a general sketch-map, so far as agriculture is concerned, but it forms a basis from which more special detailed soil surveys could be constructed by those who have knowledge of geology and of the requirements of the farmer.

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* H. B. W., 1904.

† See Hall on 'The Mechanical Analysis of Soils,' *Trans. Chem. Soc.*, 1904, vol. lxxxv., p. 950.

When our country is in possession of a complete series of Drift maps on the 6-inch scale, then, as Mr. A. D. Hall (1903) has remarked, 'the work could be rapidly supplemented by soil surveys and analyses executed by the local agricultural colleges and research institutions, until every farmer could be put in possession of that exact knowledge of the soil which is fundamental to all farming operations.'

The geologist, therefore, renders substantial aid to agriculture and many branches of sanitary science when he produces a detailed map of the subsoils. He is only indirectly concerned with the mechanical and chemical analyses which must be carried out by experts, from whom the farmer will learn the suitability of his soils for particular crops, and the best manure for supplying deficiencies in the soil.

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CHAPTER V

SUBSOILS AND SUBSTRATA

The term 'subsoil' is properly applied to the more or less weathered or disintegrated portion of the geological formation, igneous rocks or substrata, immediately beneath the soil.

It is usually devoid of humus, and is therefore more often paler in tint than the soil; nevertheless, roots and rootlets, especially of trees, extend into the subsoil, so that it contains a certain amount of vegetable matter, and the deposit may also have some organic constituents derived from the decay of fossilized plants and animals.

The subsoil is thus the direct product of the geological formation, the weathered portion of it varying from a few inches to several feet, but sometimes being imperceptible. Thus, on some formations of fairly uniform character and locally of considerable thickness, it is hardly possible to distinguish any separate subsoil, as on many areas of Chalk, on Oxford Clay, Keuper Marl, and other great clay-formations, except that the clay is often rendered brown by oxidization of the ferruginous matter. So also there may be little subsoil on certain areas of gravel, pebble beds, and sands, as well as on hard rocks that have resisted disintegration.

The true subsoil is well shown in the Oolitic limestone areas, where we have at the surface a brashy and more or less loamy soil, a foot or so in depth, merging into a rubble of weathered limestone, from 18 inches to 4 or 5 feet in thickness, resting on thin bedded limestones (used for dry-wall stone) for a foot or two, while below are the more massive stone beds employed as freestone, and unaffected by weather. The amount of weathering depends on the presence or absence of protective clay coverings.

On Plate IV., Fig. i., is a view of the Portland Stone Beds, taken by Professor S. H. Reynolds. This shows clearly the soil, the weathered and rubbly limestone or subsoil, and the more solid beds of stone beneath.

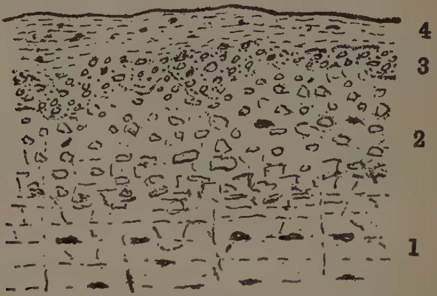

FIG. 3.—SECTION ON CROHAM PARK ESTATE, CROYDON.

4, Dark brown loamy soil, with flint stones, 6 inches to 1 foot.
3, Lighter brown earthy and chalky rubble, 6 inches to 1 foot.
2, Rubble of Chalk, 2 to 4 feet.
1, Firm, flaggy and jointed Chalk, with flints.

The Great Oolite Limestone, as seen in a quarry between Bromham and Stagsden, in Bedfordshire, is worked partly beneath a covering of Great Oolite Clay, but towards its outcrop it becomes more and more weathered, passing into rubble, then into crumbling marl, and finally into a brown calcareous loam, which is washed to some extent down the slopes.

In the neighbourhood of Croydon, the subsoil and soil on the Chalk may be well observed in places, though elsewhere both are thin (Fig. 3).

On the downs north-west of Purley the following section was noted:

Grey soil with chips of flints (downwash)	2 ft. 3 in.
Brown loamy soil, with here and there fine Chalk gravel at base	10 in. to 1 ft. 3 in.
Rubble and breccia of Chalk in matrix of chalky marl (subsoil)	2 ft.
Flaggy Chalk with flints.	

The substrata from which the subsoils are derived are made up of different types of earth and rock, varying according to the nature and changes in the geological formations, so that there are all kinds of intermediate stages, from the earthy to the stony and rocky. Gravel passes into sand, sand into loam, loam into clay, and clay into marl, and all in places may be more or less stony. Although most of the formations are termed 'sedimentary,' and were formed under aqueous conditions and by mechanical agencies, others were due to chemical and organic agencies, or to a combination of them.

The geological nature of the land has often given rise to names of places,* thus:

Clay is indicated in Claydon, Clayton, Foston-le-Clay, and Claygate; *Marl* in Marlborough, Redmarley, and Marlow; *Chalk* in Broad Chalk (Wilts) and Chalk (Kent); *Sand* in Sandwich, Santon Downham, and Sandy; *Shingle* (chesel) in Chesil Bank, Chislehurst, and Chelsea; *Pebbles* (or popples) in Newton Poppleford and Poppleton; *Red Earth* in Radstock, Ratcliffe, Rutland, and Redcar.

The following are principal lithological divisions among the sedimentary and stratified formations:

Earthy and more or less Calcareous.

Argillaceous or Pelitic.

CLAY.—In its purest form (hydrous aluminium silicate), known as kaolin, china or porcelain clay, and pipe-clay, it is barren. By the addition of siliceous matter (fine sand or silt), and of calcareous, carbonaceous, or ferruginous matter, it passes into various kinds of clay—potters' clay, plastic or tile clay, terra-cotta clay, marl, fire clay, etc., the last named with a large percentage of silica (65 per cent. at Stourbridge) and an absence of alkalies. Both in composition and texture, clay is of varied character and plasticity. Some deposits, termed 'plastic clay' in South Wales, are in reality very fine siliceous sediment, which, like Chalk sediment, becomes more or less plastic when wet. Clays frequently contain nodules of argillaceous and somewhat ferruginous limestone, known as cement stones and septaria.

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* See Isaac Taylor, 'Words and Places,' 6th edit., 1878.

Boulder Clay, or Till, is an irregular accumulation of clay and stones, etc. (See p. 228.)

The term *Clunch*, a provincial one, was applied by William Smith to portions of the Oxford Clay, 'hard clay rising in lumps,' as distinct from the shaly beds. Clunch has also been applied to beds of Chalk Marl.

SHALE.—Impure indurated clay, laminated or thinly bedded, weathering into clay; sometimes bituminous (oil-shale), as locally in the Kimeridge, Oxford, Lias, and Carboniferous shales.

The term *Parting* (as distinct from Bed) is applied to the thin seams of clay, shale, or marl, that intervene between beds of limestone or sandstone.

The term *Mother* is sometimes applied to the shale adhering to limestone; shale often passes into shaly limestone.

The terms *Rhab*, *Plate*, *Bind*, and *Blaes*, are locally applied to beds of shale.

MARL.—Calcareous clay, with 10 per cent. or more of calcium carbonate, sometimes crowded with mollusca (shell-marl); in many cases ferruginous, as in marls of the Trias, Permian, and Old Red Sandstone.

LOAM.—An admixture of sand and clay, sometimes calcareous; extensively dug for brickmaking, and commonly known as 'brickearth.' By gardeners the term is sometimes restricted to a soil of calcareous loam with humus, the top-spit of fibrous or turf loam.

Loess.—The term *Loess* is applied to accumulations of calcareous loam or silty clay, buff in colour, often of great superficial extent, of remarkable depth, and exceptional fertility—indeed, it has been described as 'the most fruitful soil in the world.'

Among the more notable regions are Northern China, where it rises to 8,000 feet above sea-level; the Russian Steppes; the Rhine Valley, where it extends to a height of 800 feet above the river; the Mississippi Valley, in the upper part of which it rises 700 feet above the river; while in parts of Iowa and Wisconsin it attains elevations of more than 1,200 feet.*

Much of it is considered to be wind-drifted or Æolian; portions are fluviatile or lacustrine, being in some cases silt derived from Glacial lakes. It contains land shells, bones of animals, and occasionally freshwater shells. Hence the composition is apt to vary, though it maintains much uniformity in general character; there is sometimes as much as 26 per cent. of carbonate of lime.

In the United States and Europe the loess or adobe may attain a thickness of 150 to 200 feet; in China it extends to depths of 1,500 to 2,000 feet or more. Although it crumbles in the hand, the loess is otherwise firm, homogeneous, and sufficiently tenacious to stand in precipitous or even vertical cliffs 200 feet high along the borders of valleys. The stability is to some extent maintained by tubular pores lined with carbonate of lime. In China numerous habitations have been excavated in the loess; in Nebraska, also, there are 'dug-outs,' as they are called.

Loess contains from 60 to 74 per cent. of silica, 8 to

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* Baron F. von Richthofen, *Geol. Mag.*, 1882; and G. F. Wright, 'The Ice Age in North America,' 5th edit., 1911, pp. 407, 413.

12 per cent. of alumina. There are also alkaline salts (potash and soda), carbonate of lime (as before mentioned), iron and manganese oxides, and phosphoric acid.

Adobe, a term applied to the loess in America, is described by Mr. G. P. Merrill as a grey-brown or yellow calcareous clay, very fine-grained, porous and friable, of great depth and wonderful fertility. It forms the soil of a large part of the rainless region of the United States and Mexico, extending from the sea-level to great elevations, and requiring irrigation. In Colorado walls and cottages are constructed of adobe, which 'may be made to set like concrete.'*

The term *Gumbo* is used in Missouri, Nebraska, and Iowa, for a deposit that occurs generally beneath loess and above Boulder Clay, or Till, graduating into both. It is a dense, sticky, and impervious clay, red, brown, yellow, and dark blue in colour, with scattered pebbles in places, and attaining thicknesses of from 10 to 40 feet. It is capable of cultivation, after being prepared by tillage when dry.†

FULLER'S EARTH.—Usually a bluish or greenish, somewhat calcareous clay, that weathers to a brown or yellow colour. It is of an unctuous character, somewhat greasy to the touch, and with a shining streak; it is not plastic, and falls to a powder in water. Occurs in the Lower Greensand of Nutfield, Surrey, and at Woburn, Bedfordshire; in the Fuller's Earth Formation, or Fullonian, of Midford and Wellow, near Bath; also at Chedworth, Gloucestershire.‡ The fulling mills may be seen in the old clothmaking districts, some being termed 'tucking mills.' The earth occurs, also, in Silurian, Lower Ludlow Beds, near Ludlow, and in the Ordovician of Vrongoch, Rhiwlas, near Bala.

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* *Nature*, July 20, 1911.

† S. W. Stookey, *Report Iowa Geol. Survey for* 1909 (1910), vol. xx., p. 180.

‡ See H. B. W., 'Memoir on Jurassic Rocks,' *Geol. Survey*, 1894, vol. iv., p. 488.

Clay at the base of Rhætic Beds (Grey Marls) was used at one time in the preparation of fuller's earth at Emborrow, in Somerset; it does not appear to have been a true fuller's earth.*

Arenaceous.

SILT.—Fine-grained, more or less muddy sand, such as the Warp of the Humber and other estuaries and alluvial areas. Liquid mud is termed 'sludge.'

SAND.—Formed mostly of quartz grains, coarse and fine, mica, felspar, occasionally with flint and chert, etc. Sometimes calcareous, as in the Midford and Portland Sands, or made up largely of comminuted shells (shell-sand), as in the Crag, certain Drift deposits, and Blown Sands. Slightly loamy in portions of the Thanet Sands. Glauconitic, as in the Portland Sands, Lower and Upper Greensand. Ferruginous in the Trias, Permian, and Old Red Sandstone. Pure white (glass) sand in places; elsewhere of various colours—yellow, brown, red, green, and black.

Quicksands are sands holding much water, as in tidal estuaries on some sea-shores, and on land in basin-shaped hollows where sand rests on clay. At the base of the Permian there is so-called quicksand, or loose and running sand. Such sand is spoken of by well-sinkers as live sand, in distinction from dead sand, which, being slightly loamy, does not readily stir when opened up.

Some sands but slightly indurated are termed 'sand-rock' or 'rock-sand,' as in the Wealden area (Hastings Beds); they readily crumble between the fingers.

Very fine-grained sands occur in the Midford Sands,

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* C. Lloyd Morgan and S. H. Reynolds, *Proc. Bristol Nat. Soc.*, 1899, ix., p. 109.

Hastings Beds, and Bagshot Beds, and in some of the so-called silica clays, more properly silica sands.

Stony.

GRAVEL.—Composed usually of hard siliceous stones, flint, chert, quartz, quartzite, grit, jasper, lydite, etc., in the form of pebbles, subangular or angular fragments; sometimes with pebbles of limestone.

There is usually a considerable matrix of sand, mostly siliceous, but sometimes calcareous, and often ferruginous.

Some gravels have a matrix so clayey that they are practically impervious, and hold up water, as in the case of certain pebbly gravels in Middlesex at Totteridge, etc.

SHINGLE OR PEBBLE BEDS.—Under this heading are included the beach deposits, or other accumulations, which consist, for the most part, of well-rounded stones, as in the case of the Chesil Bank, the Budleigh Salterton pebble (or popple) bed of Bunter age.

BRECCIA.—Composed of more or less angular rocky materials, sometimes loose, sometimes cemented into a hard rock, the rock-fragments in many cases disrupted by frost, etc., on cliffs in the form of scree or talus; in other cases produced by faults or other disturbances (fault-rock or crush-breccia).

CONGLOMERATE.—Formed of subangular gravel cemented into hard rock.

AGGLOMERATE.—Applied to ejected igneous materials in volcanic necks or pipes.

PUDDINGSTONE.—Cemented pebble gravel or shingle.

TILLITE.—This term is applied to indurated Till or Boulder Clay of Glacial origin, but formed during earlier periods than the Pleistocene.

Some deposits—siliceous, carbonaceous, and calcareous—are largely of organic origin.

Carbonaceous.

PEAT.—This vegetable accumulation occurs on hill-slopes, and in marshy tracts or bogs; the peat fuel is sometimes called 'turf,' and the ground where it is dug a Turbary.

LIGNITE AND BROWN COAL.—More highly mineralized matter of vegetable origin, approaching ordinary coal in character, and containing 67 to 72 per cent. of carbon. Woody structure is generally visible in lignite.

COAL.—(See p. 323.)

The above are Cumulose deposits, according to the classification of Mr. G. P. Merrill, as they result from the gradual accumulation of organic material, mostly *in situ* or not far drifted, and contain but small amounts of foreign detritus.

Calcareous.

LIMESTONE.—The limestones include many varieties, differing much in texture, as well as in composition. Chalk includes some of the purest forms of carbonate of lime, but the lower portions of the formation are generally argillaceous, and known as Chalk Marl, and the upper parts contain many nodules and veins of flint.

The oolitic limestones include stone composed, almost wholly in some cases, of spherical grains, like the roe of a fish (*oolite* or *roestone*), and sometimes of larger and more or less lenticular concretions, like peas or beans, when the stone is known as *pisolite*. Iron-shot limestones contain tiny spheroidal and other fragments of iron oxide, which have replaced sometimes oolites, sometimes fragments of fossils.

Earthy and argillaceous limestones contain more or less clayey matter, and pass into shaly limestones or limestone shales. Other limestones are sandy, and when thin-bedded become flagstones or tilestones. The term *Pendle* is sometimes applied to such fissile limestones, as in the case of the Stonesfield and Collyweston (so-called) 'slates.'

Earthy and shelly limestones are known as *rag* or *ragstone.*

Harder varieties, with shells, corals, etc., form *marble*, when they are of an ornamental character, and take a good polish.

Tufa or *calcareous sinter* is a friable calcareous deposit formed by springs; *travertine* is a compact and more crystalline deposit similarly formed.

KUNKUR (OR KANKAR).—This rocky material, as found in India, has been described by Mr. R. D. Oldham as a nodular or tufaceous concretionary limestone, generally of an ash-grey or dove-grey colour; it occurs both in layers or beds, often of considerable thickness and extent, and in detached nodular concretions of various sizes embedded in stiff clay.

Elsewhere in tropical regions subject to wet and dry seasons, as in Central Africa, it occurs in superficial deposits, the limestone concretions being likened by Mr. H. B. Maufe to the cornstones of the Old Red Sandstone.*

Somewhat similar accumulations are found in the desert regions of Australia, where, as remarked by Mr. J. A. Thomson, the rocks are oxidized to a considerable depth. By the reconstruction of the surface deposits, there are formed laterites, quartzites, cement, and cement gravel. The cement consists of oxidized rock-fragments bound together by calcareous matter. The cement gravel contains a good deal of concretionary calcareous matter.†

DOLOMITE OR MAGNESIAN LIMESTONE.—This occurs both as a mineral and rock. (See p. 55.) The formation known as Magnesian Limestone in the Permian consists partly of dolomite, and partly of ordinary limestone.

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* 'Summary of Progress,' *Geol. Survey for* 1909 (1910), p. 35.

† *Geol. Mag.*, 1912, p. 149.

IRONSTONE.—Iron-ore, much of it oolitic, is found in beds in the form of grey carbonate of iron, at some depth below the surface, when unweathered, and in the form of peroxide, known as brown iron-ore, at and near the surface. It occurs in the Lower Lias of Lincolnshire, the Middle Lias (Marlstone) of Oxfordshire, Northamptonshire, Leicestershire, Lincolnshire, Yorkshire (Cleveland), and on the Island of Raasay. The rock-beds are usually much fissured at the surface, owing, as Mr. J. D. Kendall has pointed out, to the general diminution in the volume of the strata by weathering processes, whereby also the iron-ore in the brown rock is more concentrated. Similar iron-ore of variable quality occurs in the Northampton Beds, above the Upper Lias, in the counties of Northampton, Rutland, and Lincoln; in the Corallian rocks of Wiltshire, Dorset, and Kent (Dover boring); and in the Lower Cretaceous of Lincolnshire. All the beds are more or less local, passing gradually into ordinary limestones. The strata yield a rich brown, more or less loamy, ferruginous soil.

LATERITE.—This is a name generally used for a red, brown, or yellow cellular clayey, quartzose, and ferruginous rock, a residual or decomposition product of varied composition, but usually containing titanium, and sometimes manganese-ore. According to Mr. R. D. Oldham, it is soft and easily cut while fresh and moist, but hardens on exposure. It is readily cut into blocks for building purposes. It occurs on hills and plateaux, and on lowlands in India, Brazil, Guiana, etc., varying a good deal in texture, being sometimes brecciated. The country, as remarked by Mr. Oldham, is usually barren, with but small trees and shrubs, the infertility being due to the pervious nature of the rock, as water sinks through it.

While much laterite is chemically formed and residual, some accumulations are detrital and transported.*

Bole is a yellow or red ferruginous, earthy, and friable ochreous clay, used as a pigment. *Lithomarge* is a hard or soft red, and sometimes bluish, mottled clay, with but little ferric oxide.

Both are derived in Antrim from the decomposition of beds of basalt. There also is obtained *Bauxite clay*, from which aluminium is manufactured. It contains 46 per cent. (and much more in other districts) of alumina, 14½ per cent. of silica, and about 2½ per cent. of ferric oxide.

Rocky.

SLATE.—Ordinary slate or clay slate (argillite) has been produced from shales and clays that have been subjected to great mechanical stresses, the pressure and shearing having caused the rock to have a cleavage independent of the natural stratification, though sometimes coinciding with it.

The term *Phyllite* is used for rocks intermediate between slates and schists.

SCHIST.—Metamorphic slaty arenaceous and igneous rocks, in which particular minerals are prominent, as Mica Slate or Schist, Talc Schist, Hornblende Schist, etc. The minerals, when arranged in alternate bands, give the rock a foliated appearance.

MUDSTONE.—Indurated sandy clay, loam, or silt.

SANDSTONE.—Indurated sand cemented by silica, etc. (See p. 54.) Hard, close-grained varieties are known as *Grits*, and they sometimes contain small pebbles of quartz, etc.

Quartzite is intensely hard sandstone, in which the siliceous cementing material has become more or less blended with the quartz grains, generally owing to metamorphic action.

* See L. L. Fermor, *Geol. Mag.*, 1911, p. 454, etc.

Some varieties of fine-grained sandstone, with clayey matrix and usually micaceous, are termed *Psammites*.

Sandstones, when fissile or readily split into thin slabs, are known as flagstones and tilestones (usually more or less calcareous).

Thin sandstone bands in shale are locally known as *Girdles* (Northumberland).

CHERT.—Siliceous rock, often of organic origin, and not truly separable from flint,* occurs in massive beds in Carboniferous rocks of Devon (Codden Hill Beds), Yorkshire, etc.; also in the Portland Beds, Upper and Lower Greensand.

LYDIAN STONE (or Lydite) consists of silica, with alumina and carbonaceous matter, and is usually black. Rocks of this character, with a flinty or cherty appearance, may be produced by contact-metamorphism of igneous rocks or shale, which is altered to a hornstone or hornfels, as in the Lias at Portrush.

ARKOSE.—Applied to detritus of granite, or other felspathic rocks, which has been more or less solidified or cemented into a hard rock.

Among subsoils and substrata there are many varieties of colour, especially in the estuarine deposits of the Oolitic Series, the Wealden Beds, and Reading Beds; also in the Bagshot Beds, notably in Alum Bay, in the Isle of Wight. The 'Painted Desert' of Arizona is a remarkable example of brightly-coloured strata. The various tones of red and brown are due to peroxide of iron. Many blue clays and limestones owe their colour to the presence of iron bisulphide (pyrites in a finely-divided state), or to carbonaceous matter. In the former case the pyrites, by processes of weathering (air and moisture), is converted into iron sulphate, and eventually, by decomposition, it may become converted into hydrated peroxide of iron, the sulphuric acid, as noted by Fream, uniting with some of the earthy or other bases in the soil, such as alumina, lime, magnesia, etc. (See p. 22.) Thus the London Clay, blue or bluish-grey at a depth of 5 feet or more from the surface, has become weathered or rusty in mass in the upper part, and along cracks or courses taken by roots and rootlets lower down.

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* W. Hill, 'Flint and Chert,' *Proc. Geol. Assoc.*, 1911, xxii., p. 61.

Blue limestones and clays are changed into pale grey, and whitish limestones and clays by the action of the weather. This occurs, though not very prominently, in the Lower Lias of Somerset, near Keinton Mandeville, and near Chard. Analyses by Dr. W. Pollard showed that the change from blue to whitish is due to the disappearance of the organic matter and the pyrites, brought about by the action of the weather.*

Some mottled limestones are stained irregularly by bituminous matter, originally derived from organisms.

Blue veins in alluvial deposits are often due to phosphate of iron (vivianite).

Green colours are due to the presence of chlorite, or of glauconite, as in the Portland Sands, Upper and Lower Greensand, and Bracklesham Beds.

Grey marls often appear much darker when wet. Some very dark brown or black layers in gravel and sand are due to the presence of manganese-ore, or to protoxide of iron, or to peaty matter.

The table on p. 51 gives the principal types of igneous rock, which may be grouped in different ways according to their mode of formation (see p. 4), their crystalline characters, and chemical composition.

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* 'Summary of Progress,' *Geol. Survey* for 1904 (1905), p. 169.

		Contemporaneous.		Intrusive.	
		Volcanic or Effusive. Tuffs and Lavas.		*Hypabyssal.* Dykes and Sills.	*Plutonic.* Laccolites and other Massive Rocks.
Ultrabasic.	—	—	—	—	Peridotite. Serpentine.
Basic.	55 to 45 per cent. Silica.	Tachylyte.	Basalt.	Dolerite.	Gabbro.
Intermediate.	65 to 55 per cent. Silica.	Andesite Glass. Trachyte Glass.	Phonolite. Andesite. Trachyte.	Lamprophyre. Porphyrite.	Diorite. Syenite.
Acid.	Over 65 per cent. Silica.	Pumice. Obsidian.	Rhyolite.	Pitchstone. Felsite. Quartz-porphyry and Elvan. Granophyre.	Granite.
		Glassy	*Finely crystalline*	*Mostly crystalline*	*Holo-crystalline*

MINERAL INGREDIENTS OF IGNEOUS ROCKS.

The general mineral composition of the principal igneous rocks is as follows:

ANDESITE.—Plagioclase (Labradorite), Hornblende, with Augite, etc.

BASALT.—Plagioclase, Augite, often Olivine and Iron-ore.

DIABASE.*—Plagioclase, Augite, with Apatite, Iron-ore, etc. (Contemporaneous, and in dykes and sills.)

DIORITE.—Plagioclase, Hornblende, etc.

DOLERITE.—Plagioclase (Labradorite), Augite, often Olivine, Iron-ore.

ELVAN.—(Microgranite or Quartz-porphyry.)

EPIDIORITE.—Plagioclase, Hornblende. (A metamorphic igneous rock of basic character, such as Dolerite, that has undergone great pressure accompanied by chemical change.)

FELSITE.—Plagioclase, Orthoclase, Quartz (Felstone).

GABBRO.—Plagioclase, Diallage, often Olivine, Iron-ore.

GRANITE.—Quartz, Orthoclase or Plagioclase (Felspar), Biotite or Muscovite (Mica).

GRANOPHYRE.—Quartz, Orthoclase, etc.; sometimes Augite and Biotite.

GREENSTONE.—(General term applied to Basalt, Dolerite, Diabase, Diorite, and Gabbro.)

LAMPROPHYRE (including Minette or Mica-trap).—Biotite, Augite, with Quartz, Olivine, and Apatite.

MICROGRANITE.—(Fine-grained Granite, as Elvan.)

OBSIDIAN.—(Glassy volcanic rock.)

PERIDOTITE.—Olivine, Augite, Hornblende.

PITCHSTONE.—Glassy rock, with tiny imperfect crystalline structures (crystallites and microlites).

PHONOLITE.—(Clinkstone), Sanidine, Nepheline, etc. (usually porphyritic).

PORPHYRITE.—Plagioclase (porphyritic), with Biotite, Hornblende, or occasionally Augite.

QUARTZ-PORPHYRY.—Quartz, Felspar, sometimes Biotite, etc.

RHYOLITE.—Quartz, Felspar (Orthoclase, etc.).

SERPENTINE.—Ferro-magnesian-silicate (occurs both as a mineral and rock).

SYENITE.—Orthoclase, Hornblende; sometimes Augite, Biotite, etc.

TACHYLYTE.—(Glassy volcanic rock.)

TRACHYTE.—Orthoclase (Sanidine), with Augite, Hornblende, etc.

TRAP.—(A general term, applied to bedded Basalt in particular, but also to various Greenstones and other igneous rocks.)

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* Term now abandoned by A. Harker, 'Petrology for Students,' 4th edit., 1908, p. 138.

The modern volcanic soils of Italy, Sicily, the West Indies, etc., are largely made up of fragmental volcanic materials. The finer, known under the general name of Tuffs, include volcanic ashes, dust, mud, or sand, also fragments of lava or lapilli, with the local varieties of earthy and cemented ash, such as Peperino, that occurs near Rome; Pozzuolana, near Naples; Palagonite-tuff, in Sicily; and Trass—a somewhat mixed accumulation of volcanic detritus, etc., in alluvial tracts—in the Eifel. Coarse materials include scoria or cinders and pumice; vesicular or scoriaceous substances derived from the surface of lava; volcanic conglomerate and breccia, made up of rounded or angular materials, chiefly of igneous rocks.

The ingredients of the igneous rocks are in the main original crystalline aggregates or *essential minerals*, with, in many instances, also certain *accessory minerals*, such as topaz, beryl, sphene, garnet, etc.

Secondary minerals are those produced subsequently to consolidation by weathering processes, the chemical action of surface and deep-seated, often thermal, waters, etc. The cavities in lava may be filled with calcite, quartz, chalcedony, zeolites, talc, chlorite, etc., forming amygdaloidal rocks.

The term 'porphyry' (or porphyritic) is applied to finely crystalline igneous rocks, in which prominent crystals, usually felspar, but sometimes quartz, etc., have been developed.

The minerals in sedimentary rocks occur mostly as derived and worn fragments, due originally to the waste of igneous rocks, and subsequently incorporated again and again in later sedimentary strata, especially in those of a sandy, loamy, and clayey nature. Of such minerals quartz is the most abundant; there also occur micas and felspars, manganese-ore, magnetite, rutile, tourmaline, garnet, topaz, zircon.

Sundry minerals occur in the form of nodules or concretions, in seams or veins, the last-named of a date subsequent to the consolidation of the strata. Thus quartz, calcite, etc., occur in veins and cavities. Elsewhere we find glauconite, concretions of carbonate of lime, known as 'race,' and fibrous seams, known as 'beef'; also nodules of flint, chert, ironstone, and phosphatic matter. Some minerals occur as cementing materials.

It is well known that many rocks, notably the freestones, or limestones and sandstones used for building purposes, are comparatively soft when quarried at a depth, but harden when dry, after exposure at the surface. It is important that they be not used in the 'green' state, fresh from the quarry, but that they undergo a proper amount of seasoning. The quarry-water contains a certain amount of soluble silica, carbonate of lime, and iron oxides, and these are deposited in crevices of the rock and on the exterior after evaporation of the quarry-water.

Rocks may be naturally hardened underground or at the surface by cementing materials; in some cases purely siliceous, or calcareous, or ferruginous; and Mr. G. W. Lamplugh has applied the terms 'silicrete,' 'calcrete,' and 'ferricrete,' to such indurated rocks, according to whether the cement is silica, calcite, limonite or hæmatite.

Loose siliceous sands, with the aid of siliceous cement, become hard Greywethers or Sarsen stones, and pebbly sands become puddingstone. Other sands have become hardened into layers of sandstone, or into spheroidal masses known as 'doggers,' by carbonate of lime or calcite.

The bedding or false bedding of the sands is often well seen in these doggers, but when the stratification is not oblique, the upper or under layers, which may be split off from the surface, are known in the Cotteswold Hills as 'pot-lids.'

Again, sands and gravels are indurated by ferruginous matter to form Pan or Iron Pan. (See p. 196.)

Some conglomerates, like the Dolomitic Conglomerate in the Keuper of the Mendip Hills and South Wales, have a matrix of magnesian limestone, with much ferruginous matter. Gypsum, barytes, and celestine, act as cementing materials, as in certain Triassic sandstones.

Some of the shelly Blown Sands are indurated by carbonate of lime into hard rocky bands. In the plain of Qâ, Sinai, according to T. Barron, Blown Sands have been bound by common salt and carbonate of lime.

The composition of the more abundant minerals in the sedimentary and igneous formations is as follows:

Calcite (Calc-spar).—Calcium carbonate (rhombohedral crystals).

Aragonite.—Calcium carbonate (rhombic crystals); more easily dissolved than calcite.

Dolomite.—Calcium and magnesium carbonates: usually with calcium fluoride and chloride.

Gypsum.—Calcium sulphate. Occurs in isolated crystals as *Selenite;* also in granular and fibrous masses, nodules, and veins. The more compact masses capable of polish are known as *Alabaster*. *Anhydrite* is an anhydrous variety.

Apatite.—Calcium phosphate.

Magnetite (Magnetic Iron-ore).—Iron peroxide and protoxide.

Hæmatite (Red Iron-ore).—Iron peroxide (anhydrous).

Limonite (Brown Iron-ore).—Iron peroxide (hydrous).

Pyrites (Iron-Pyrites).—Iron sulphide: in separate crystals, or in nodular masses.

Barytes (Heavy Spar).—Barium sulphate.

Celestine.—Strontium sulphate.

Quartz.—Silica. *Chalcedony* is obscurely crystalline silica, and *Jasper* is silica with alumina, coloured by iron oxide.

Felspars:

- *Orthoclase* (and variety *Sanidine*) (Potash Felspar).—Potassium and aluminium silicate.
- *Plagioclase*
  - *Oligoclase*
    Labradorite (Soda-lime Felspars).—Sodium calcium and aluminium silicate.
  - *Albite* (Soda Felspar).—Sodium and aluminium silicate.

Hornblende.—Magnesium, calcium, aluminium, and iron silicate.

Augite.—Calcium, magnesium, aluminium, and iron silicate.

Diallage.—(Variety of Augite.)

OLIVINE.—Magnesium and iron silicate.

NEPHELINE.—Aluminium, potassium, and sodium silicate.

MICAS:

Muscovite (White or Potash Mica).—Potassium and aluminium silicate.

Biotite (Black or Magnesia Mica).—Potassium, magnesium, iron, and aluminium silicate.

TALC.—Magnesium and iron silicate, with sometimes alumina.

CHLORITE.—Magnesium, aluminium, and iron silicate.

WAD AND PSILOMELANE.—Manganese oxides.

GLAUCONITE.—Iron and potassium silicate, with often alumina, magnesia, and lime.

[*For composition of Igneous rocks, see table opposite.*]

GENERAL CHEMICAL COMPOSITION OF THE SEDIMENTARY FORMATIONS.

Analyses of the sedimentary geological formations vary so much from place to place that no useful purpose would be served if a series of detailed analyses were here given.

It should be mentioned, however, that in 1897 Professor D. A. Gilchrist organized the work of examining the soils of Dorset for the University College, Reading, under a grant made by the Dorset County Council. A series of reports with analyses of soils and subsoils was published (1899 and following years), and in 1906 the general results were embodied in a Report by Professor John Percival. In these publications* there are particulars relating to the Lias and Oolites, the Wealden and Upper Cretaceous strata, the Eocene, Valley Gravels, and Alluvium.

Further, the 'Report on the Agriculture and Soils of Kent, Surrey, and Sussex,' by Mr. A. D. Hall and Dr. E. J. Russell (1911), gives analyses of the soils and subsoils relating to the various Wealden, Upper Cretaceous, and Eocene strata, Valley Gravels, Brickearth, and Alluvium; while Mr. Hall's 'Book of the Rothamsted Experiments' (1905) supplies information relating to the mixed soils and subsoils of the Clay-with-flints.

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* Issued by the Agricultural Department, University College, Reading.

GENERAL CHEMICAL COMPOSITION OF THE MORE PROMINENT IGNEOUS ROCKS.

[*Figures indicate percentages.*]

Components.	Symbols.	Granites.	Quartz-Porphyry Felsite.	Rhyolite.	Syenite.	Diorite.	Andesite.	Trachyte.	Gabbro.	Dolerite.	Basalt Lava.	Basalt.	Serpentine.	Volcanic Tuffs.
Silica ...	SiO_2	68–74	72	75	51–64	52–54	63	62½	46½	50	46½	51¼	38¾	54–60
Alumina ...	Al_2O_3	12 17	14	13	9–18	15–19	14¾	19	26¼	12¾	15¼	14	3	15–21
Ferrous oxide	FeO	1 2	2 3	⅕	not estimated	5	3	1¾	3	11½	.7¾	8¾	5	—
Ferric oxide	Fe_2O_3	1	1	3	5–18	4	1½	3½	2	3¼	3½	4¼	1¾	5–9
Lime ...	CaO	1–7	½	1	4–10	6½–7¾	4¾	1¾	15¼	8¾	10	8¼	trace	2–4
Magnesia	MgO	¼–2½	1	1⅕	2–4	5–7¼	2¾	1½	5	4½	8½	4½	34½	¾–1¾
Potash ...	K_2O	1¼–6½	6½	4½	1½–3	2½–3½	2	5	⅕	½	½	1¼	—	4½–7
Soda ...	Na_2O	1¼–4	½	2½	2 4	2–3½	4	2½	1½	5¼	2½	3	—	4–6
Manganese oxide	MnO	½	½	—	trace	—	—	¼	⅐	not estimated	⅐	⅙	—	—
Phosphoric acid	P_2O_5	trace	—	—	½	—	—	—	trace	½	⅒	¼	—	—
Titanium oxide	TiO_2	—	—	—	—	—	—	—	⅙	1⅓	1¾	2½	—	—
References to authorities and localities		General	J. A. Phillips, Cornish Elvan	General, N. Wales and N. England	E. E. Berry, Charnwood Forest	J. J. H. Teall, N.W. Highlands and Zirkel (average)	T. Waller, Cheviots	J. S. G. Wilson, Jedburgh	W. Pollard, Skye	W. Henry, Rowley Rag	W. Pollard, Skye	J. J. H. Teall, Whin Sill, Durham	J. A. Phillips, Lizard	G. P. Merrill, General

All that we need give here will be notes on the general composition of some of the sedimentary formations.

LIMESTONES.

Analyses give the amounts of calcium carbonate as follows:

	Per Cent.
Woolhope Limestone, Shropshire	64
Carboniferous Limestone, Black Mountains	98
Lower Lias Limestone	76–86
Inferior Oolite Series, Ham Hill Stone	79
" " " Ancaster Stone	93
Great Oolite, Bath Stone	94
Middle Chalk, Wiltshire	93
Upper Chalk, Kent	98½

Some have a considerable amount of silica and alumina. They mostly contain small amounts of magnesia, and iron oxide; some have calcium sulphate and phosphate, and a few have iron bisulphide, manganese dioxide, sodium chloride, and potash.

MARLS AND CLAYS.

Analyses of *Red Marl*, Worcester, showed 5 per cent. of calcium carbonate, the bulk of the marl being silica (quartz) and aluminium silicate, with small amounts of iron oxide, calcium sulphate, magnesia, potash, and soda.

Chalk Marl of Cambridgeshire and Hertfordshire showed 50 to 76 per cent. of calcium carbonate, with aluminium silicate, colloid silica, and quartz, and small amounts of calcium sulphate and phosphate, magnesium carbonate, potash, soda, iron, and (occasionally) manganese oxide.

Fuller's Earth (blue), Midford, Somerset, showed, on analysis by J. Hort Player,* silica 54, alumina 18·6, ferric oxide 3·9, ferrous oxide 0·8, magnesia 2·3, soda 0·7, potash 1·8, and carbonic acid 3·4, per cent.

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* 'Jurassic Rocks of Britain,' *Geol. Survey*, vol. iv., p. 491.

Lower Lias Clay, associated with limestones, Keinton Mandeville, Somerset, showed, on analysis by Dr. W. Pollard,* 20·31 per cent. of calcium carbonate, with 50·33 of insoluble matter (aluminium silicate, etc.), a little calcium sulphate, iron-bisulphide, and organic matter.

Kimeridge Clay.—Analysis, by Mr. J. W. Keates, of the bituminous shale, known as Kimeridge coal, showed volatile matter 61·0, carbon 13·15, and ash 25·85, per cent. The ash consisted of aluminium silicate, iron peroxide 7·10 per cent., and insoluble residue of 29 per cent.

Gault Clay from Folkestone, analyzed by Professor J. B. Harrison,† contained 29·20 per cent. of calcium carbonate, with 33·81 of aluminium silicate, 12·82 of quartz, 8·41 of colloid silica, also a little calcium phosphate and sulphate, and organic matter.

London Clay, analyzed by Mr. J. H. B. Jenkins,‡ showed 67·9 per cent. silica and 18·3 alumina.

The Lower Lias, Gault, and London Clays, contain small variable amounts of iron oxide, magnesia, potash, and soda.

SANDSTONES.

Old Red Sandstone, Shropshire, analyzed by Mr. Philip Holland,§ showed 77·23 per cent. of insoluble matter, and 7·42 of soluble silica, with small amounts of titanic oxide, lime, alumina, ferric and ferrous oxides, manganese oxide, magnesia, potash, soda, and phosphoric acid.

The *Millstone Grit* of Bristol, analyzed by Mr. E. B. Wethered,‖ contained 97·80 silica, and less than 1 per cent. each of alumina, iron oxides, lime, and carbonic acid.

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* 'Summary of Progress,' *Geol. Survey* for 1904, p. 169.

† 'Cretaceous Rocks of Britain,' *Geol. Survey*, vol. i., p. 317.

‡ *Geol. Mag.*, 1908, p. 266.

§ *Proc. Liverpool Geol. Soc.*, 1907, 1908.

‖ *Quart. Journ. Geol. Soc.*, 1883, xxxix., p. 215.

The Silica Stone, or 'clay,' in the Millstone Grit of South Wales, contains 95 to 97 per cent. silica, with small amounts of iron oxide, alumina, magnesia, potash, and soda.

Among the *Wealden Sandstones*, or Hastings Beds, a sample of Tunbridge Wells Sand contained 94 per cent. silica, 2·5 ferric oxide, 2·0 magnesium carbonate, and 1·5 alumina.[*]

In the *Lower Greensand*, the Kentish Rag of the Hythe Beds is exceedingly variable; samples from Maidstone have contained 72 per cent. of silica in one case, and 92 per cent. of calcium carbonate in another. In the former case small quantities of magnesia, potash, and ferric oxide, were present, together with 12½ per cent. of lime, etc.[†]

In the *Upper Greensand*, the Malmstone of Hampshire, according to analysis by Professor J. B. Harrison, contained 15½ per cent. calcium carbonate, 35 of colloid silica, 34 of aluminium silicate, with small quantities of ferric oxide, lime, magnesia, and alkalies.[‡]

It may here be noted that the more abundant saline ingredients in spring and river waters are—[§]

Calcium carbonate.
" sulphate.
Magnesium carbonate.
" sulphate.

Sodium carbonate.
" chloride.
" sulphate.
Silica.

In mineral and thermal waters, the ingredients are usually more varied and greater in amount.[§]

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[*] Topley, 'Geology of the Weald,' *Geol. Survey*, 1875, p. 367, etc.

[†] P. G. Sanford, *Geol. Mag.*, 1889, p. 73.

[‡] Jukes-Browne, 'Cretaceous Rocks of Britain,' *Geol. Survey*, 1900, vol. i., p. 327.

[§] See H. B. W., 'Geology of Water-Supply,' 1910, pp. 276, 287.

CHAPTER VI

WEATHERING OF ROCKS AND SUBSIDENCES

Rocks are broken up or disintegrated, decomposed, and dissolved by various natural agencies—Mechanical, Chemical, and Organic.

The harder rocks are often much jointed or cracked, owing to shrinkage on consolidation, and to subsequent ruptures by faults and disturbances caused by earth movements. Surface agents have therefore been readily able to act on the exposed fissures. The depth to which rocks are altered by these processes of weathering is sometimes termed the 'zone of oxidation.'

Mechanical Agents of Disintegration.

Apart from the mechanical action of running water in wearing or tearing away and transporting earthy and stony materials from the surface, the action of frost, and sometimes of lightning, in disrupting the rocks, may be seen in the loose detritus and screes along mountain and craggy hill-slopes. Frost, too, if long continued, raises the surface-level of the ground, and hard and soft rocks and earths become disarranged. (See p. 83.) Exposed rock-surfaces in Polar regions, as pointed out by Professor J. Geikie, are pulverized by frost, which produces grit, sand, and finer dusty material, which is shifted by winds.

Great changes of temperature, diurnal and otherwise, thus cause the rupture of exposed surfaces of various rocky materials. As an example, the schists of Lukoma, in Lake Nyassa, split and flake off by the daily and nightly changes of temperature.*

Chemical Agencies of Decomposition and Dissolution: Subsidences.

Rain-water and springs holding carbonic acid gas in solution are potent agencies in the dissolution of calcareous deposits. The gas is, in the first instance, derived from the atmosphere, and afterwards, to some extent, from the air in soil.

Such rocks as Chalk, Carboniferous Limestone, may lose, by dissolution in carbonated water, 90 per cent. or more of calcic carbonate. (See Figs. 4 and 5.)

Decalcification also takes place in Gravels that contain limestone pebbles, and in the chalky Boulder Clay. The results in these cases are pipes (sand-pipes or pot-holes), or other irregular cavities that contain a residue of red earthy material, with nodules of flint in the case of the Chalk (Clay-with-flints, mixed often with gravel and Eocene débris; see p. 34), and with chert from the Carboniferous Limestone; while on the faces of the limestone fossils may be left standing out in relief.

In other cases bands of jointed limestone become weathered into a rubble that finally yields a brashy soil.

Calcareous sandstones are similarly decalcified, losing their cementing material so as to become loose sands; while some ferruginous limestones, as in the case of the Marlstone, near Yeovil, are decomposed at their outcrop into a ferruginous earth. The calcareous sandstone of the Upper Greensand, as on Salcombe Hill, near Sidmouth, is furrowed by pipes.

Some limestones are converted into rotten stone, as in the Carboniferous Limestone Series (Upper Limestone

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* C. Maples, *Scot. Geograph. Mag.*, 1888.

Shales) of South Wales and elsewhere; this is due to decalcification of beds of black limestone, that contain about 16 per cent. of silica in a fine state of division, the residue, or rotten stone, containing about 84 per cent. of silica.*

Chert becomes decomposed, as in the Upper Greensand of Dorset, into a clayey earth.

By dissolution of limestone rocks along fissures, immense caverns have been formed, especially in the Carboniferous Limestone, in some cases in the Magnesian Limestone. The Magnesian Limestone, which, when formed of granular dolomite, presents a very sandy appearance, also locally contains much silica, as at Mansfield, and when decomposed it may leave a loose granular or sandy accumulation.

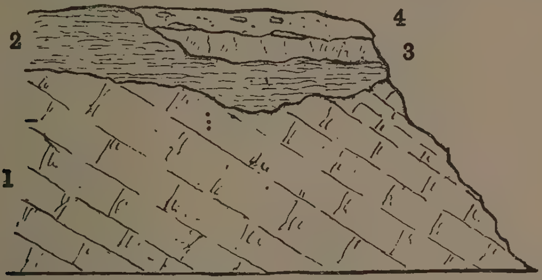

FIG. 4.—SECTION IN WATERY COMBE, WEST OF CHEWTON MENDIP, SOMERSET.

4, Loamy soil, with fragments of Lower Lias, White Lias, and Carboniferous Limestone, 5 inches.
3, Mottled marl (possibly a relic of Rhætic marl), 6 inches.
2, Reddish-brown clay (residual earth), with limonite (brown iron-ore) and fragments of Carboniferous Limestone, up to 1 foot 3 inches.
1, Carboniferous Limestone.

Great cavities, some 100 yards across, and perhaps old swallow-holes, occur at Brassington, near Wirksworth, and near Hartington, in the Carboniferous Limestone, infilled with white clays, and coloured sands with quartzite pebbles, a mixture, perhaps, of altered Carboniferous Shale and Bunter Beds.

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* A. Strahan, 'Geol. Merthyr Tydfil,' *Geol. Survey*, 1904, p. 121.

The clays were formerly dug for use at the Derby Porcelain Works.* Pockets of white clays also occur in the Carboniferous Limestone near Mold, Oswestry, and Llandudno.

The term 'Famp' is applied to the insoluble residue left after dissolution of impure Carboniferous Limestone, as in Teesdale, where the erosion is often marked by a hollow in the ground.

In the Limestone and Dolomite region, known as the Karst in Southern Austria, 'the stony Arabia of Austria,' which is much faulted, the ground, like that in parts of the Carboniferous Limestone districts of Northern England, is cut up by clefts and swallow-holes, so that the rain rapidly disappears, and much underground erosion takes place. (See p. 77.) The dissolution of the white limestones yields a red earthy soil, known as *terra rossa*.†

Darwin (1881, p. 137) remarked that the pipes in the Chalk are still in process of formation. 'During the last forty years I have seen or heard of five cases in which a circular space, several feet in diameter, suddenly fell in, leaving on the field an open hole, with perpendicular sides, some feet in depth. This occurred in one of my own fields whilst it was being rolled, and the hinder quarters of the shaft-horse fell in; two or three cart-loads of rubbish were required to fill up the hole. The subsidence occurred where there was a broad depression, as if the surface had fallen in at several former periods. . . . The rain-water over this whole district sinks perpendicularly into the ground, but the chalk is more porous in certain places than in others. Thus the drainage from the overlying clay is directed to certain points, where a greater amount of calcareous matter is dissolved than elsewhere. Even narrow open channels are sometimes formed in the solid chalk. As the chalk is slowly dissolved over the whole country, but more in some parts than in others, the

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* H. H. Arnold-Bemrose, 'Geology in the Field,' *Geol. Assoc.*, 1910, p. 554.

† E. Tietze, *Geol. Mag.*, 1874, p. 321.

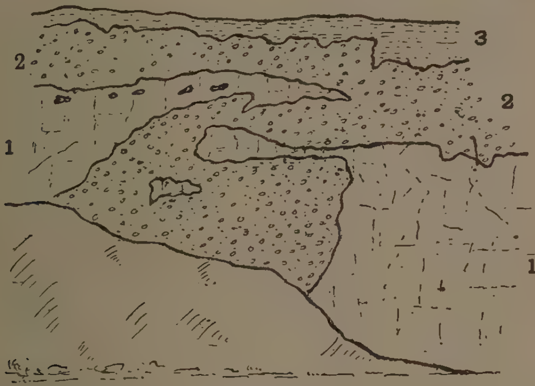

FIG. 5.—SECTION BY MILL, NORTH OF STOKE HOLY CROSS, NORFOLK.

3, Loamy soil.
2, Gravel and sand, chalky in places, with a small apparently isolated mass of Chalk.
1, Chalk-with-flints, somewhat broken and crumbly in places. Greatest depth seen, 12 feet.

undissolved residue—that is, the overlying mass of red clay-with-flints—likewise sinks slowly down, and tends to fill up the pipes or cavities. But the upper part of the red clay holds together, aided probably by the roots of plants, for a longer time than the lower parts, and thus forms a roof, which sooner or later falls in, as in the above-mentioned five cases.'

A. W. Morant pointed out that when the sewage of Norwich was conveyed on to the farm at Whitlingham, the land upon which it was discharged was soon covered with circular holes, mostly from 3 to 5 feet in diameter, and of various depths; and on one occasion the ground suddenly subsided for a space of 21 feet in diameter, and to a depth of 12 feet. These holes were evidently due to the 'sand-galls' in the Chalk, and to the washing in of material by the excess of water.*

Cavities in valley gravel overlying Chalk or other limestone, due to similar causes, have been met with in the Valley of the Little Ouse in Norfolk, and near Bedford.

Mr. A. C. G. Cameron has recorded an instance at Baldock, when a ploughman and lad with three horses were at work, and a portion of land suddenly caved in. He noted that subsidences have taken place in Hertfordshire over shafts sunk for Chalk and subsequently filled in, and further mentioned an instance where a haystack in course of erection suddenly disappeared down a cavity, in the Magnesian Limestone near Ripon, during the time when the haymakers had adjourned for dinner.†

Huge natural pits, more or less circular and tapering downwards, described by the Rev. O. Fisher, occur on the heaths of Affpuddle and Puddletown, between Dorchester and Wareham, where Eocene strata rest on the Chalk. One hollow, known as Cull-pepper's Dish, had a circumference of 290 yards, with sloping sides extending to a depth of 47 yards.

In Jamaica the white limestone of Oligocene age forms a large plateau, known as 'the cock-pit country,' on account of the numerous swallow-holes, which, according to Mr. R. T. Hill, vary from shallow basins to sink-holes 500 feet deep.

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* *Engineer*, li., p. 123.

† *Geol. Mag.*, 1888, p. 25. See also Rev. J. S. Tute, *ibid.*, 1868, p. 178; and J. H. Charnock, *Journ. Roy. Agric. Soc.*, 1848, ix., p. 291.

The conversion of ironstone beds from carbonate to ferric oxide leads to disruption of the rocks by loss of carbonic acid. (See p. 47.)

Artificial subsidences have been caused by the abstraction of brine from the rock-salt beds in Cheshire, and occasionally by the falling in of the roofs of old rock-salt mines. The hollows, as mentioned by Dr. A. Strahan, sometimes form broad shallow lakes, known as 'flashes'; one at Northwich occupies about 100 acres. But of different origin are the meres of Delamere Forest, which are shallow basins in Drift sand overlying Keuper Marls. Workings for coal have also led to serious subsidences of the land.

The igneous rocks, whether granites or greenstones, are decomposed so irregularly that hard rocks jut out in places alongside of material so soft that it can be dug with a spade.

Crystalline rocks containing much silica, and more or less disintegrated by mechanical agencies, may be decomposed so as to lose as much as 40 or 50 per cent. of their mass, the greater loss* being in lime, magnesia, and the alkalies, less in silica, with a proportional increase in the amounts of alumina and sometimes of iron oxides in the decomposed material.

Basalt often exhibits a spheroidal structure that has been produced during cooling and contraction of the molten mass. Segments of columnar joints, as noted by Sir A. Geikie, may also weather into spheroidal masses. When weathered, the rock exhibits harder egg-shaped masses, which exfoliate or scale off in shells, as in Fig. i., Plate II.

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* G. P. Merrill, 'Rocks, Rock-Weathering and Soils,' p. 234.

The most intense decomposition is that of the granites which, as in Cornwall and Devon, have locally passed into China clay, with quartz crystals and a certain amount of mica.*

The weathering of granite along the planes of joints, some vertical, some more or less horizontal, leads to the formation of great blocks with rounded edges that form tors and rocking-stones. (See Fig. 6.)

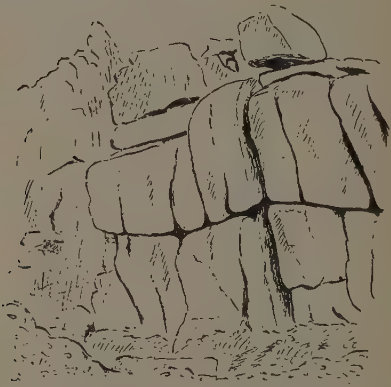

FIG. 6.—GRANITE ROCKS, WEST OF ST. LEVAN, LAND'S END, CORNWALL.

Diagram to show jointing in granite, with Logan Rock to right. (From a photograph.)

The decomposition of granite by mechanical, chemical, and organic agencies, has been well told by Mr. Alexander Johnstone.†

Taking a specimen of Aberdeenshire granite from

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* See W. A. E. Ussher, D. A. MacAlister, and J. S. Flett, in 'Geology of Bodmin and St. Austell,' *Geol. Survey*, 1909, p. 105.

† *Nature*, September 29, 1892, p. 517.

PLATE II.

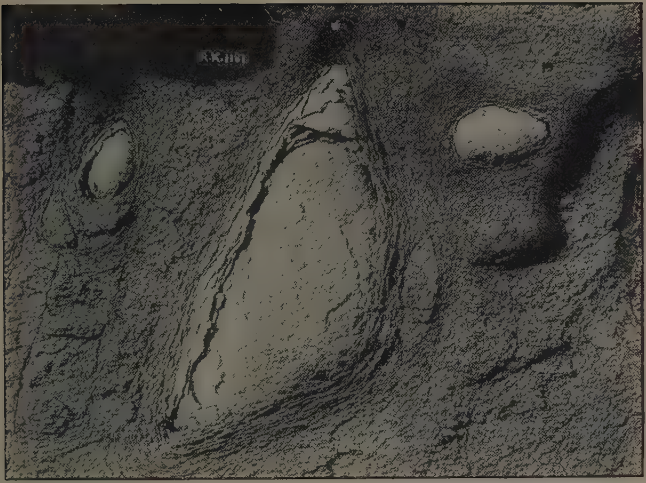

Photo by R. Kidston.

(i.) WEATHERED SPHEROIDAL BASALT, STIRLING.

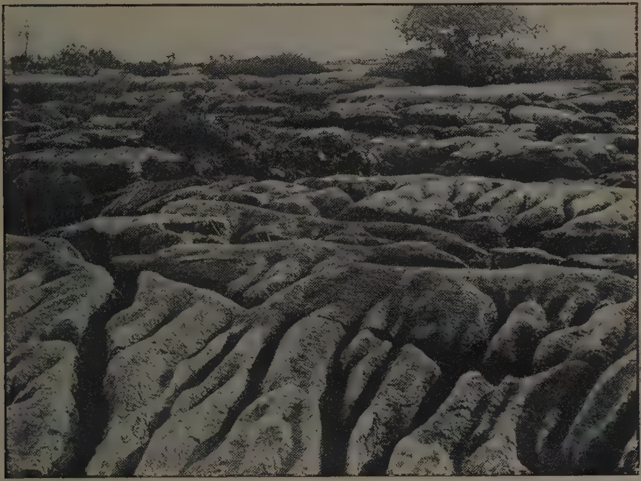

Photo by Godfrey Bingley.

(ii.) WIDENED JOINTS, OR 'GRIKES,' AND RAIN-GULLIES IN CARBONIFEROUS LIMESTONE, NEAR GRANGE, LANCASHIRE.

Kemnay Quarry, on Donside, he found that the unweathered rock gave the following general percentages:

	Per Cent.
Orthoclase felspar	42
Quartz	22
Biotite mica	20
Plagioclase felspar	9
Hornblende	3¼
Muscovite mica	2
Magnetite (and ilmenite)	1
Pyrites	½
Apatite	¼
	100

In the process of weathering, he noted that the first change is in the peroxidation of some of the iron. Lines of rust are produced, and these lead to miniature 'weather-joints,' distinct from the large joints and fissures of shrinkage and rock movement. The weather-joints are acted on mainly by frost, and the rock surfaces are broken up. The carbonic acid gas of the atmosphere and rain decomposes the felspars, biotite, and hornblende, the felspars giving rise to clay (kaolin), carbonate of potash, and soluble silicates of potash and soda.

The biotite loses magnesia, which is removed as carbonate, and iron in the form of oxide or carbonate, and it remains in the condition of white or yellow muscovite.

The hornblende loses its lime in the form of carbonate, some magnesia as carbonate, most of its iron as oxide and carbonate, manganese as oxide, sodium and potassium (if present) as carbonates or soluble silicates. The residue (hydrated silicate of magnesia, iron, and alumina) may undergo further changes in the production of magnesia-clay, 'to which the greasy feel of soils is due.' A small amount of sulphate of iron arises from the decomposition of the iron pyrites.

The influence of changes of temperature, percolating water, and the pressure of roots, help in minor degrees the production of the soil. Lichens succeeded by mosses supply organic elements (humus) necessary for the fertility of the soil; bacteria also commence their operations. As the soil becomes deeper there is an increase in the sulphates, owing to the further and more rapid decomposition of pyrites.

The following approximate composition was given by Mr. Johnstone as fairly typical of a good granite soil in the Valley of the Don, in Aberdeenshire:

		Per Cent.
Insolubles	Pure clay and steatite	10
	Quartz and secondary silica	20
	Muscovite	4
Substances capable of transformation (mainly Orthoclase)		60
Injurious solubles	Humic acid, soluble silicate, and sulphate of iron	1·3
Non-injurious solubles	Phosphates of lime, magnesia, potash, soda, etc.	0·3
	Sulphates of lime, potash, soda, magnesia, etc.	0·8
	Nitrates of lime, potash, soda, magnesia, etc.	0·3
	Carbonates of lime, potash, soda, magnesia, etc.	0·1
	Chlorides	trace
Water and air (mechanically held) in dry summer		3·2
		100·0

Mr. F. P. Mennell has remarked that the rains during the wet season in Rhodesia prevent the accumulation of kaolin on the granite areas, but do not remove all the ‘sand’ formed of quartz, and sometimes largely of felspar, and this gives rise to some of the best soil in the country.*

Organic Agencies Affecting Soils.

The influence of various burrowing animals—worms, ants, termites (white ants), and moles, as well as rabbits, foxes, and badgers—and in Manitoba and other parts of North America of burrowing rodents, known as 'pocket-gophers,' tends to stir up the soil and subsoil in various ways, and to promote the decomposition of rocks. The influence of bacteria is elsewhere noted (p. 107).

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* ‘Geology of Southern Rhodesia,’ 1904

Lichens and mosses likewise help in the process of decay, while the mechanical power exerted by roots, especially of trees, aids in the general disintegration.

On the other hand, grassy and woodland tracts have a protective influence against the direct wear and tear of rain, although the material thrown up in worm-castings, ant and mole hills, is liable to be washed or blown away; sometimes it may be carried into fissures that extend into the subsoil. Ant-hills are objectionable in pasture-lands, as they spoil grass and occupy space. In some parts of the United States their mounds are from 1 to 2 feet high, and from 3 to 5 feet in diameter.

CHAPTER VII

SURFACE SOILS

THE general term 'soils' is often and rightly used to include both the top or surface soil and the subsoil.

The true soil has been described as that part of the surface which is capable of being cultivated; and the term is sometimes restricted by farmers to the portion turned over in ordinary ploughing, which may be from 3 to 8 or 10 inches in depth, whereas in subsoil-ploughing the land is broken up to a depth of from 14 to 18 inches. The actual depth of soil, however, cannot be so limited, as will be noted farther on.

It is evident, however, that there are two main types of surface soil—the natural or virgin, that has not been cultivated, and the more or less artificial or cultivated soil, which is a modified condition of the natural soil.

NATURAL SOILS.

Soils are primarily due to the decay of the underlying subsoils or substrata from which their chief mineral ingredients are derived. The decomposed portion varies in depth according to the nature of the rocks. If hard and siliceous, the subsoil consists of hard angular fragments; if hard and calcareous, the rock is liable to be dissolved by the action of rain-water holding carbonic acid in solution, irregular cavities are formed, and the residue which goes to form the soil is a red earth of varying thickness and extent, bare rock appearing here and there at the surface.

Calcareous sandstones or sandy limestones decompose into a loose sandy and earthy soil; clays weather into a somewhat stiff loamy soil of no great thickness, as a rule; while loams give rise to deeper loamy soils, of good texture and usually of great fertility. This subject has been dealt with in a previous chapter, and reference has also been made to the fact that the distribution of soils in general is directly related to that of the underlying geological formations.

The soil, as a rule, merges downwards into the subsoil, and that again into the substrata or unweathered geological formation.

Soils in general contain in most abundance silica, alumina, and lime. Other important ingredients are dealt with later.

Alumina, in the form of silicate of alumina or clay, is of most service in modifying the texture of soils, in absorbing and retaining moisture, and thereby aiding the solution of mineral plant-food. It further serves as a binding material, useful in holding the roots of plants. It is seldom absent, except in loose siliceous sands.

More important are the constituents derived from the decay of organic matter, animal and vegetable, and especially vegetable matter, to the decomposition of which is due the *humus*, the black or brown matter which constitutes from 2 to 9 per cent. or more of the mould or soil in many cultivated fields, and still more prominently in gardens. Virgin soils, where clearances of woodland have been made, naturally contain much leaf-mould.

All soils may be regarded as in the main of sedentary origin—they are local or indigenous. Some are residual, being due to chemical decomposition of the substrata; others, as described by Mr. G. P. Merrill (1897, p. 299), may be cumulose, as in the case of peaty accumulations; but in most cases the primary ingredients are the pulverized, shivered, or shattered materials mechanically derived, or the residues obtained by dissolution from the subsoil or substrata.

Alluvium, peat, sand-dunes, and the various Glacial deposits, are included under geological formations, and should not be classed as transported or erratic soils. Although we may make exceptions in the case of material dispersed over lands by river-floods, or artificially introduced, as in the Warp of the Humber, yet otherwise the alluvium, when not subject to floods, yields its different surface soils and subsoils just as do the Glacial Drifts. Both formations, however, do contain in themselves the transported materials of soils of modern or ancient date.

The truly transported materials of soils are those wind-drifted or shifted from higher grounds, as rain-wash, débris from cliffs, the materials carried downwards by avalanches, landslips, etc. All these materials may be shifted over, or to a certain extent incorporated with, the most sedentary of soils, and they are not always beneficial. (See p. 221.) Light, sandy, and peaty soils, are also liable to be drifted by the wind.

Adventitious material is naturally added to the soil by wind from expanses of dry sand and sandhills bordering the sea-coast, as well as from desert tracts and inland exposures on sandy heaths, some of it purely siliceous. Other varieties are calcareous and more beneficial. This may be the case also with dust from roads (the proverbial March dust), dried mud from the borders of tidal rivers and estuaries, volcanic ash, and meteoric dust. (See p. 89.)

Saline particles are carried by wind and rain from the spray of sea-coasts, and dead leaves in the later autumn are scattered over fields from adjacent woodlands.

It has been remarked that 'the very dust we tread upon was once alive,' and this was true as regards powder from certain road-stones, such as limestone, flint, and chert, of organic origin; but these materials and other organic matter are not so abundant since the more general use on roads of igneous rocks and quartzites, and especially since tar-paving and motor vehicles came to be introduced.

In the Holderness district there are sandy and loamy soils that appear to have been entirely wind-drifted, and to have no direct connection with the subsoil. (See p. 239.)* Indications of such soils should be given on geological maps.

Residual soils are usually distinct in general appearance and character from the underlying rock, as in the residual red clays and earths derived from limestones, which sometimes have but 1 or 2 per cent. of calcium carbonate.

The red soil of Bermuda, as remarked by Mr. Merrill (1897, p. 358), is sometimes so rich in iron-ore as to be deleterious; it is derived from coral and shell limestones, the residue amounting to about 1 per cent. of the decomposed rock. The blue-grass soils of Central Kentucky, as the same writer points out (p. 382), are limestone residues, celebrated for the luxuriant growth of *Poa pratensis*. Other residual soils, as already noted, are due to the decomposition of various igneous rocks, where the constituents have undergone chemical changes.

CULTIVATED OR ARTIFICIAL SOILS.

Soils are greatly modified, mechanically and chemically, by processes of cultivation, by tillage, drainage, and the application of manures. (See pp. 112, 119, 129.)

The processes of claying or marling have added much calcareous matter, and have considerably altered the nature of both light and heavy lands. Soil has also been carried on to certain rocky and barren tracts. (See p. 332.)

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* C. Reid, 'Geol. Holderness,' *Mem. Geol. Survey*, 1885.

Soils occasionally contain stones quite foreign to the district. They have sometimes been brought with marl, such as Boulder Clay, which contains many varieties of rock; or with farmyard manure and road-scrapings, the stones being gathered from material used for road-mending, and obtained from a distance. Beach-stones may be brought with seaweed when that is put on the land. Sometimes material tipped to form a railway embankment leads to the scattering of rock-fragments or pebbles over portions of adjacent fields. Instances have occurred in Somerset where holes made by the removal of the shelly sands of the Burtle Beds have been filled up with Red Marl, to the manifest confusion of the geological surveyor.

Made Soil or *Made Ground* is found especially in towns of ancient date, where it is composed largely of fragments of brick, tile, and stone, with much earth and rubbish: materials from old buildings, and road-metal. Under London the made soil is sometimes nearly 30 feet thick, and in it burnt earth, due to the Great Fire of 1666, has in places been observed.

The thickness of soils varies from a few inches to a foot or more under ordinary circumstances in fairly level ground, where the soil has been formed mainly *in situ.* As a rule, a good soil should not be less than 6 inches thick, but a greater depth is advantageous for the roots of most plants.

On mountain-slopes and less elevated but steep eminences of hard rock there is little or no soil, as the finer weathered material of the rocks is washed down, together with the larger fragments dislodged by frost, to form slopes of earthy and angular débris or screes.

Again, on some of the great limestone plateaux in West

Yorkshire the Carboniferous Limestone is so fissured that any soil formed is almost wholly washed away, and bare rocky tracts remain. (See Fig. ii., Plate II.) This may occur on other fissured rocks. Ground cannot be cultivated on hard rocks that are not readily disintegrated, as the soil when present is very thin, and often occurs only in patches.

In arable tracts, along escarpments and hill-slopes, but little soil can accumulate (as already noted), although in some cases hedgerows with good banks prevent the further downwash. (See Fig. 7.)

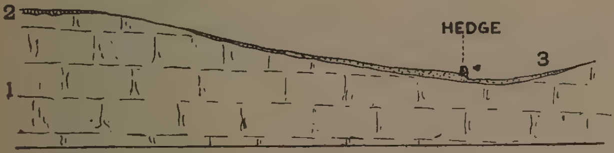

FIG. 7.—SECTION NEAR CROHAM HURST, CROYDON.

3, Brown loamy and flinty soil, lighter in tint on higher slope.
2, Remnants of Thanet Sand and Reading Beds.
1, Chalk-with-flints.

On clays and on the Chalk the soil is often thin or 'fleet,' whether on slopes or uplands.

The greater thicknesses of soil naturally are found along the foot of the gentler slopes of hills formed of comparatively soft or readily decomposed strata, and on old pastures in level grounds where the action of earthworms has been potent.

Hence, many of the uplands, and especially the bottoms and lower gentle slopes of valleys, yield the deeper and better soils, those in the lower grounds being as a rule the more fertile. On some gravelly and sandy areas where the soil is thin the mould or humus is washed down, and the ground rendered less productive.

When the soil is 1 foot or more in depth, the nature of the subsoil is less important, if the ground be naturally or artificially drained. Deep ploughing may be injurious when the soil is thin, and beneficial where it is more than 6 or 8 inches thick, but a good deal depends on the nature of the subsoil.

In Essex, as the writer was told, there is an old saying among farmers that—

> ‘When the clay doth feed the sand,
> Then ’tis well for England :
> But when the sand doth feed the clay,
> Then for England lack-a-day !’

The surface soils, like the subsoils, exhibit every gradation from one type to another, and they are classified partly according to general texture, partly according to composition, as follows:

*Symbols.**	*Soil.*	*Substrata.*
cl.	Clayey (up to 95 per cent. clay)	Kimeridge Clay, Gault, London Clay
st. cl.	Stony or gravelly clay (sometimes chalky)	Boulder Clay
fl. cl.	Flinty clay	Clay-with-flints
l. cl.	Loamy clay or clay-loam (up to 85 per cent. clay)	London Clay
m.	Marly (up to 20 per cent. calcium carbonate, but very variable)	Chalk, Chalk Marl, Keuper Marl
l.	Loamy (up to 70 per cent. clay)	Brickearth, Bracklesham Beds, Middle Lias
st. l.	Stony or gravelly loam	Boulder Clay
s. l.	Sandy loam (up to 40 per cent. clay)	Bagshot Beds, Upper Greensand, Old Red Sandstone
slt.	Silty (fine earthy or muddy sand)	Alluvium, Warp
slt. l.	Silty loam (very fine-grained sandy loam)	Alluvium, etc.

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* The symbols here given are those that may be useful to record on geological maps. (See p. 33.)

Symbols.	*Soil.*	*Substrata.*
s.	Sandy (siliceous)	Some Blown Sand, Bagshot Sand, Lower Greensand
s.	Sandy (siliceous and calcareous)	Some Blown Sand, Middle Lias, Midford Sand
b.	Brashy (earthy, and often sticky soil, with weathered lumps of limestone or stonebrash)	Cornbrash and other limestones of the Oolitic Series
f.	Ferruginous (earthy)	Carboniferous Limestone (residue)
f. s., f. l.	Ferruginous (sandy and loamy)	Ironstone Beds of Middle Lias, Corallian, etc.; Keuper and Bunter Sandstones
p.	Peaty (heath or bog-earth, peaty sand with humus, and black muck soils)	Mountain slopes, moors, commons, woodlands, bog and marsh lands
g.	Gravelly and pebbly	Valley and plateau gravel, Blackheath Beds, Bunter Pebble Beds
x.	Mixed (soils varying much within limited areas)	Clay-with-flints, Woolwich and Reading Beds

This grouping of soils is but general—no two authorities appear to agree on particular definitions—the fact being that precision is impossible. Moreover, the texture of soils with the same mineral condition will vary in arid and humid regions.*

HUMUS.

Darwin (1881) remarked that, in every moderately humid country, mould, generally blackish in tint, a few inches thick, and of uniform fineness, is found on various subsoils.

Earthworms swallow much earth, together with partially decayed leaves, etc., and all so-called vegetable mould has passed many times through the intestinal canals of worms, their castings being injected over or near the surface. In woodlands the castings are to be found beneath and above the dead leaves, and the rich humus, known as leaf-mould or forest-mould, is thus formed. Worms may burrow to depths of 7 or 8 feet, and they drag leaves into their holes, which ultimately collapse.

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* See Fream and Ainsworth-Davis, 1911, p. 15; Nisbet, 1894, p. 97; and Dr. E. J. Russell, 'Report on First International Agro-Geological Conference,' *Nature*, August 4, 1910, p. 157.

From his long-continued and patient observations, Darwin found that about one-fifth of an inch of earth was annually spread on the surface of the land by worms, and thereby stones became gradually buried. In some areas on the Chalk Downs worm-castings consist largely of calcareous matter, but this is not the case in other Chalk tracts, where 3 or 4 inches of mould is to be found. At Silchester the mould was stated by Darwin to be from 9 to 20 inches thick, and he gave instances where castings would amount to from 7½ to 14½ tons per acre. In many parts as much as 10 tons annually per acre was estimated by him.

Warington remarked that a tract of unworkable clay, if laid down to grass for several seasons and subsequently ploughed, yields an excellent friable soil. Here the beneficial agency of worms is apparent, and land to some extent exhausted may thus be gradually improved. On arable land worms do little to increase the surface soil, and the good effects produced by them on grass-land would sometimes appear to have been over-estimated.*

F. H. King (1899, p. 94) has remarked that there is more humus in temperate than in tropical and arid regions. In arid regions humus may even be wanting, and yet the percentage in the soils of nitrogen is larger than in humid lands.

Humus is supplied to the land by the application of farmyard manure, and the ploughing in of stubble or green crops.

It contains carbon, hydrogen, oxygen, nitrogen, and the mineral matters derived from the plants forming it;* hence it is capable of supplying plants with the three most important plant foods—potash, phosphates, and nitrogen: the last-named through the aid of bacteria.† Too much humus, as in the case of peaty lands, is not good.

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* Dr. Somerville, 'Agriculture,' 1912, p. 71.

The *Black Earth* (*Tchernozem* or *Chernoziom*), which forms rich corn and grass-lands in Southern Russia, Hungary, and Siberia, appears to be intimately connected with the loess, of which in general it forms the top soil. These deposits, as noted by Murchison, occur on rocks of all ages and at various levels. The black earth owes its colour of dark brown and black to the amount of humus or vegetable mould, which may be as much as 12 per cent. It also contains sandy and argillaceous matter, with a little potash, soda, and phosphoric acid. Intercalations of black earth and loess have been observed. The black earth, 2 to 4 feet (more or less) in thickness, is not due to the decay of extensive forest growths, but to the decomposition of grasses and steppe plants in areas that are naturally drained. Woodlands border the region, but do not naturally extend over the black earth; and when trees are planted, the black soil is removed, so as to allow of the more ready percolation of rain-water.

As remarked by Dr. W. F. Hume,‡ to whom we are mainly indebted for the information here given, 'The original virgin steppe is fast disappearing before the advance of cultivation.' It 'easily sucked up the atmospheric moisture which fell upon its surface, whereas on the ploughed land the rain-water collects in the form of minor torrents, sweeps away the rich earth, carrying it down into the river-valleys and alluvial flats.' Moreover, the black earth soil is readily shifted by the winds, 'the traveller who crosses the steppes having his face blackened on the side which is windward, whereas the other remains perfectly clean.' Thus, some soil is removed in clouds of dust, and, further, owing to destruction of forests in the higher reaches of the rivers, much rich soil is carried away by flood-waters, no longer kept in check by the woodlands.

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* According to Nisbet (1894, p. 32), beech-leaves, which are rich in potash, form good mould; the hornbeam and chestnut also form good mould; the lime-leaves yield a small amount of humus; but oak-leaves, owing to the presence of tannic acid, do not supply good humus.

† Dr. Somerville, *op. cit.*, p. 60.

‡ *Geol. Mag.*, 1894, pp. 307, 349; also analysis by Dr. A. Voelcker in R. Damon's 'Geology of Weymouth,' etc., 1884, p. 108.

On some of the plains of Australia, and in the American prairies, there occur rich black loamy soils of similar character, and more or less calcareous, as in Iowa, Minnesota, Dakota, and Montana, where they form good wheat-lands.

A black loam of great fertility also occurs over the Drift area of Corstorphine, west of Edinburgh.

Regur is the term applied to the black or greyish-black argillaceous cotton soil of India, an accumulation from 6 to 8 feet thick. It is of alluvial origin, and derived to some extent from basaltic and various other rocks. Thus it varies in composition, but is generally retentive of moisture.

Of mixed soils, the *Podzol* of Russia, as described by Professor Glinka, consists of sands, loams, and clays, locally calcareous, but generally poor in mineral plant food. The soil is white when dry, and the land is much covered with forests, marshes, and lakes.

The red 'Buckshot' soils of Louisiana are described by Mr. Merrill as stiff clayey alluvial soils, mottled with ferruginous spots.

There are some tracts of land so stony that it might be thought that no crop could well be raised, and, indeed, the ground would be sterile if there were no sandy, loamy, or clay matrix. The stones then aid in retaining moisture.

On the Clay-with-flints in parts of Buckinghamshire and Hertfordshire this exceedingly stony soil is met with, consisting mostly of flints, some little worn, some broken, and others more or less rounded.

The stones on some fields are often gathered for road-metal, for which purpose they are well suited; but, according to a popular notion, they 'grow again.' The fact is that the stony surface is renewed in arable lands by the soil being washed down among the lower layers of flints, and to some extent fresh stones are ploughed up, whereas in pasture-lands stones become buried in process of time by worm-castings.

Thus, as Darwin related (1881, pp. 139, 143), a stony field, thickly covered with small and large flints, was converted into pasture-land in 1841, and thirty years later not a single stone was to be seen, the surface being made up of mould 2½ inches thick. He also observed that fragments of Chalk used for dressing land became buried to a depth of 7 inches, and more or less rounded in the course of twenty-nine years (see p. 131). It has likewise been observed* that, in the grass-land on the Clay-with-flints at Rothamsted stones are not abundant near the surface, owing to the length of time the land has been in grass.

With regard to the so-called 'growth' of stones, Mr. G. P. Merrill (1897, p. 393) has remarked that in New England Drift boulders removed from fields have been replaced by others through the heaving action of frost, which penetrates to a depth of 2 or 3 feet. The water-soaked clay under the boulders freezes, and expands upwards; after frost the soil sinks, but the boulders are supported by soil that falls into any cavity. Large boulders derived from Glacial Drift, and encountered when the land was taken into cultivation, as in Norfolk,

* A. D. Hall, 'The Soil.'

have sometimes been left in pasture-lands as rubbing-posts for cattle, while many have been placed here and there along highways.

Where great accumulations of gravel and boulders and tumbled blocks of rock occur, the land may not repay the cost of the removal of the larger masses. This appears to be the case in parts of Skye. (See Fig. i., Plate III.)

In some of the small areas of cultivated land in the Faröe Islands the boulders have been carried away, and a quantity of soil has been brought from the valleys and spread over the higher tracts of ground.*

In Connemara,† also, material has been carted from the beach to put on the rocky lands to form soil.

In County Galway, and elsewhere in Ireland, in districts of Carboniferous Limestone, the land has a barren rocky appearance, on account of the stone fences, the crags of rock, and the many large isolated blocks of rock.

In Dorset and Devon, where cherty detritus has been washed from the uplands of Upper Greensand over slopes of Lias Clay and Red Marls, there is a clayey soil, with many chert stones of varying thickness, with little actual subsoil. Cherty débris is also distributed over the slopes of the Foxmould Sands or lower part of the Greensand. In these cases a map showing cherty soil would afford no indication of the substrata. (See Fig. ii., Plate III.)

Soils, like subsoils, vary in tint, although as a rule the colours are not so brilliant as in some of the mottled or variegated substrata. The darker soils owe their tint mostly to humus, but this does not apply to dark shaly and slaty soils. The various colours of yellow, brown, and red, are due to the presence of ferruginous matter and

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* J. Currie, *Scot. Geograph. Mag.*, 1906, xxii., p. 141.

† J. Connolly, 'Report of the Royal Commission on Coast Erosion,' 1909, vol. ii., part ii., p. 312.

PLATE III.

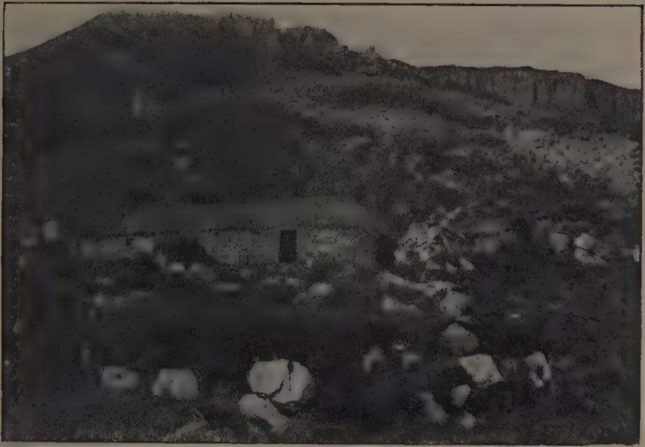


Photo by A. Evelyn Barnard

(i.) CROFT AND WEATHERED DOLERITE, VALTOS, SKYE.

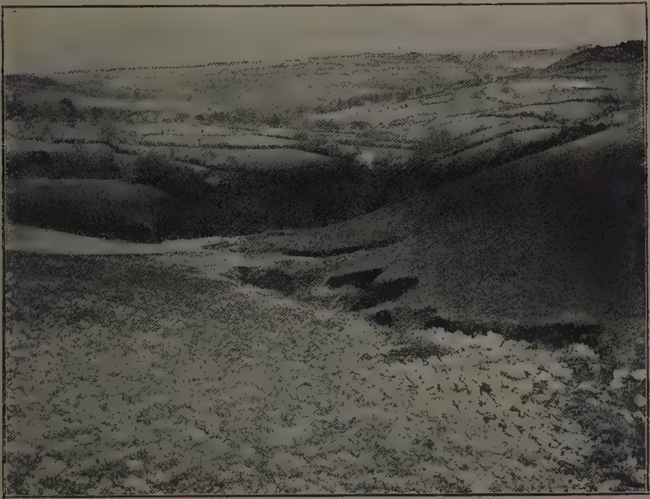
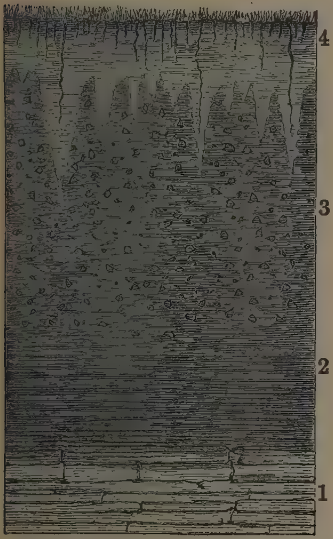


Photo by W. P. Young.

(ii.) RAIN-GULLEY, WEST OF UPLYME, DEVON.

processes of oxidation. (See p. 49.) Brighter as well as deeper soils often occur in non-glaciated regions, as compared with those which have been over-ridden by ice, and have not been exposed to weathering agents for so long a period.

The bleaching of soils and subsoils, of sand and gravel, noticeable on many heathy and moory grounds, is due to the decomposition of the ferric oxide by water containing peaty or humic acids, the iron being converted into the soluble carbonate and being leached out. (See Figs. 8 and 9.)



4, Grey soil and subsoil of loam, with roots of plants which have apparently caused a bleaching and loss of ferric oxide.

3, Red loamy Drift (rearranged Keuper Marls).

2, Keuper Marls.

1, Keuper Sandstone.

Depth of section, about 8 feet.

FIG. 8.—SECTION IN RAILWAY-CUTTING BETWEEN CODSALL AND ALBRIGHTON, SHROPSHIRE. (G. Maw.*)

In the Magdalen Islands, in the Gulf of St. Lawrence, as described by Dr. J. M. Clarke, there are purple-red sandstones, and in nearly every section of these red rocks there is a thin but persistent covering of pure white glistening sand, decoloured by organic acids.

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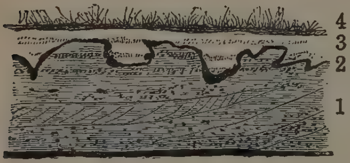
* *Quart. Journ. Geol. Soc.*, 1868, xxiv., p. 374.

The characteristic odour of soil is attributed to some volatile organic substance, of which the chemical nature has not been satisfactorily determined. On this subject C. Tomlinson has remarked that 'pure alumina gives off no odour when breathed on or wetted. The fact is, the peculiar odour referred to belongs only to impure clays, and chiefly to those that contain oxide of iron. . . . Pure kaolin, ground up in a mortar with a small quantity of water, emits a slight odour, which, however, becomes much more sensible if a little sesquioxide of iron be added.' He further referred to the fact that 'smooth quartz pebbles, when rubbed together, give an electric spark, and a fetid odour,' whether the stones are gathered from sea-beach, inland gravel, or ploughed land. Bloxam suggested that the spark and odour might be due to the presence of ozone.†



4, Black peaty soil.
3, Bleached gravel.
2, Irregular black carbonaceous band.
1, Ochreous gravel, with sandy beds showing oblique lamination.
Depth of pit, 5 feet.

FIG. 9.—SECTION IN GRAVEL-PIT NEAR EASTHAMPSTEAD, BERKSHIRE. (J. Prestwich.*)

Other rocks, such as certain limestones, give off a fetid odour when broken, as in the case of some beds of

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* *Quart. Journ. Geol. Soc.*, 1890, xlvi., p. 161.
† Tomlinson, *Proc. Geol. Assoc.*, 1862, i., p. 242.

Carboniferous Limestone. The odour may be due to bituminous matter, or it may be sulphurous, and due to the decomposition of pyrites.

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CHAPTER VIII

CLIMATIC AND OTHER PHYSICAL CONDITIONS AFFECTING THE SOILS AND AGRICULTURAL OPERATIONS

Climate has been described as 'the average of seasonal atmospheric conditions,' while the atmosphere 'is directly the source of 95 per cent. of the material in the total plant, and of 98 per cent. of the matter in the grain of corn.' The explanation is that 'heat, light, moisture, and the supply of gases, operate to control the supply of those ingredients that are furnished by the soil, and that constitute in the main the ash of the plant.'*

It is reckoned that an annual rainfall of not less than 20 inches is requisite for successful agriculture in most localities, as in Britain; that a rainfall of 25 to 35 inches is adapted for arable lands; and, when the amount is as much as 40 inches, that lands suitable for the purpose should be given up to grass. The average annual rainfall for the British Isles is 39·5 inches, as based on the records of thirty years (1870-1899); but during that period there was a maximum of 53 inches in 1872, and a minimum of 30·5 inches in 1887. In England the average is 31·5, in Wales 49·5, in Scotland 47, and in Ireland 42, inches.†

Along the south-west coast of India the annual rainfall may amount to 30 feet or more, and on the southern slopes of the Himalayas to 35 or 40 feet. In Polar regions, the annual snowfall may represent from 8 to 15 inches of water.

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* 'Relations between Climate and Crops,' by H. B. Wren, *Nature*, September 12, 1901, p. 493.

† *Nature*, December 10, 1903.

Rain is, in general, the purest natural form of water, inasmuch as it contains the smallest amount of solid ingredients in solution.

The atmosphere everywhere contains a certain but variable amount of dust, from the region of the highest mountains to the lowlands, the amount as a rule being larger in the low-levels, and especially over cities.[*] This dust includes the following mineral, vegetable, and animal matters, which may in various localities be brought to the soil:[†]

Cosmic or Meteoric dust, containing magnesium, metallic iron, cobalt, nickel, silicon, sulphur, phosphorus, and carbon.

Volcanic dust, whitish-grey ash. (See p. 115.)

Smoke dust, soot and particles of coal.

Blown Sand and mud, from deserts, sea-shores, cliffs, lake, and river-banks.

Mixed dust, mineral and organic matter, including tarry matter, and micro-organisms from roads, ploughed fields, the decay of building materials, etc.

Flue dust, lead, silver, copper, nickel, manganese.

It has been estimated that the amount of soot produced annually in Leeds amounts to about 35,000 tons, of which 48 tons is permanently, and 3,472 tons temporarily, deposited in the city, the bulk being blown farther away.[§]

While air consists of 78 per cent. nitrogen, 21 per cent. oxygen, and 1 per cent. argon and other gases, it contains nearly 3 volumes of carbonic acid in 10,000.

Nitric acid, sulphuric acid, ammonia, and sodium chloride, are brought to the earth by rain in variable amounts according to the situation. Sodium chloride is always present in rain, notably near the sea-coast, whence the spray is carried inland. In British Guiana an amount equal to about 186 pounds of common salt per acre is reckoned to be brought yearly to the land near Georgetown. At Cirencester the annual amount is estimated at about 37 pounds, and at Rothamsted 25 pounds, per acre.

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[*] *Cf.* J. Aitken, *Nature*, February 27, 1890, p. 394; January 28, 1892, p. 299; C. Reid, *Geol. Mag.*, 1884, p. 165.

[†] See W. N. Hartley and H. Ramage, *Nature*, April 4, 1901, p. 552.

[‡] *Proc. Roy. Soc.*, A., 1911, lxxxv., p. 271. The dust in the atmosphere of Dublin was found by Mr. W. N. Hartley to contain copper, lead, nickel, iron, manganese, calcium carbonate, etc.

[§] See Cohen and Ruston's 'Smoke: A Study of Town Air,' 1912, p. 19.

Sulphuric acid from rain is estimated at Rothamsted to be about 17 pounds per acre yearly, and ammonia to be 2·6 pounds. The total average annual rainfall brings nearly 5 pounds of nitrogen per acre, as ammonia, nitrates, and nitrites.* This rainfall during the years 1853 to 1903 has averaged 28·21 inches, the lowest record for one year being 18·56, and the highest 38·69, inches.

Floods along river-valleys and over broad tracts of marsh or fenland are caused by excessive rain, the rapid melting of snow on the hills, sometimes by the choking of a river with ice, or by the bursting of artificial embankments bordering rivers or tidal estuaries. Along the higher river-courses raised waterways for mills are obstructions when the river is swollen, causing the bordering ground to be inundated.

When streams take their rise in mountainous tracts of hard rock or in clayey regions, the effects of heavy rain are soon felt. It is well to remember that the low grounds along river-valleys, when liable to floods, are not suitable grounds for habitations. (See p. 199.)

On the more porous strata the effects of heavy rain are not so rapid, since much of the water sinks underground to issue as springs. When floods result, however, they are liable to cause more injury, as the streams rise gradually and the floods may last longer. Temporary floods in winter may benefit the alluvial grounds, but in summer they may injure lands under arable cultivation.

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* A. D. Hall, 1905.

Although the higher grounds as a rule receive the greater amount of rainfall, much of this is conveyed to the lower grounds, which are therefore liable to become the wetter.

Climatic conditions again affect the general agricultural features of a country. Thus, to take a well-known instance in the West of England, the climate is mild, moist, and more equable than in the East, which is comparatively dry, colder in winter, and warmer in summer. Consequently, in the former area we have more extensive areas of pasture and dairy farms, with orchards, green crops, and tracts where oats and a certain amount of barley are cultivated. In the East more land is under arable cultivation, and the soils have more influence on the character of the crops, such as wheat and barley.

As an instance of the change of conditions due directly to climate may be cited the case of the Karroo sandstones and shales, which form desert areas in Cape Colony, but yield rich and deep soils in the less arid climate of the Southern Transvaal and Orange Colony.*

The temperature of the soil and subsoil varies considerably, and has a considerable influence on the physical and chemical processes that are taking place, including the action of bacteria.† In temperate regions the zone of constant temperature may be at a depth of about 50 feet, and above that the seasonal changes affect the strata. In tropical regions the temperature is, for the most part, constant to a depth of a few feet. In Arctic regions the subsoil is frozen permanently to a depth of several hundred feet, but the surface soil may thaw between June and August to depths of from 6 inches to 4 or 5 feet, sometimes to the bed-rock.

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* G. S. Corstorphine, *Proc. Geol. Soc.* (South Africa), 1907, p. xix.

† Warington, 1900, p. 139.

In the Yukon Valley, Alaska, alternate layers of earth, or gravel and ice, are met with beneath a superficial layer of 'muck,' boggy or peaty material, which is sometimes more than 10 feet thick, and 'possesses a remarkable power of keeping the gravel beneath it permanently frozen throughout the summer.'*

F. H. King (1899, p. 220) has given the following statistics of soil temperatures (Fahrenheit):

	April.		May.		June.		July.		August.		September.	
	1	2	1	2	1	2	1	2	1	2	1	2
Depth, 6 in.	43·1	44·6	54·7	56·8	66·3	61·1	69·7	67·2	68·5	64·0	61·7	58·2
„ 12 „	42·7	44·3	53·8	57·5	65·0	60·0	68·9	66·1	68·6	63·6	62·7	57·8
„ 24 „	41·4	44·4	51·4	53·6	61·9	59·1	66·4	63·1	67·4	63·5	63·6	58·8

1, Pennsylvania State College. 2, Munich (loam).

He states that, according to Ebermayer (of Munich), the lowest soil temperature 'at which the processes of growth are started in most cultivated crops is from 45° to 48° F., but the maximum results are attained only after the soil has reached a temperature of 68° to 70° F.' He further observed that the soil temperature of a sandy loam in August was from 5° to 7° F. warmer than that of a clay loam at depths of from 1 to 3 feet.

The influence of sunshine is important. Sand or loam heats rapidly at the surface, but the warmth does not penetrate, while dense clay transmits warmth.† Peaty and other dark soils absorb heat, while the pale clayey, chalky, and other soils, reflect it. Schübler estimated the power in soils of retaining heat as follows: Calcareous sand, 100; siliceous sand, 95; sandy clay, 76; loamy clay, 71; stiff clay, 68; grey clay, 66; humus, 49.* The difference in the scorching effect of the sun on grass in areas on gravel as compared with similar areas on clay is very noticeable. During the prolonged drought of 1911 in Great Britain, 'the inability of the sun to penetrate the clay was proved by an experiment on August 9, which was the hottest day, with a shade temperature of 96° F. It was then found that 6 inches below the surface the temperature of the earth was no more than 76° F.'†

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* H. A. Miers, 'Yukon,' 1901, p. 8.

† Dr. H. R. Mill, *Trans. Sanit. Inst.*, xv., p. 174.

It has been observed by F. H. King that the rolling of land tends to make it warmer during bright clear weather, but in cold and cloudy weather it has the opposite effect. He also notes that warm and cold soils are dependent on the amount of water held and brought to the surface for evaporation, those holding most and delivering it most rapidly being cold.

Snow serves to prevent the escape of heat, and to check the depth to which frost can penetrate.

Soil has sometimes been artificially heated by the blowing in of steam, which improves the fertility. The heating effect of farmyard manure, and especially of the stable manure used by gardeners, may here be mentioned, and the Rev. O. Fisher has called attention to well-water in a farmyard that was supposed to indicate a thermal spring, but evidently had been influenced by the heat of fermenting manure.‡

Professor T. C. Chamberlin has remarked that radioactive matter is found 'in practically all the rocks of the surface of the earth, in practically all the waters, and in practically all the atmosphere. But this highly diffusive distribution has not been uniform. . . . So far as the accessible part of the earth is concerned, the igneous rocks may be taken as the original source of the radio-active substances.' From the igneous rocks they 'are dissolved and disseminated through the waters, and carried wherever they go; while from both the rocks and the waters, the emanations are given forth into the atmosphere.' Further, it appears 'that the radio-active substances are leached out of the parent igneous rocks faster than the average minerals of those rocks, for weathered igneous rocks are found to carry less radio-active matter than fresh rocks.' Nevertheless, soils 'still retain notable radio-activity, but a part of this is probably a redeposit from the atmosphere. In general, it appears that the clayey element carries more radio-active material than the quartzose sands or the calcareous derivatives.'*

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* *Journ. Roy. Agric. Soc.*, 1840, i., p. 201.

† *Morning Post*, August 31, 1911.

‡ *Geol. Mag.*, 1871, p. 42, and F. W. Harmer, *ibid.*, p. 143.

Percolation, Capillarity, and Evaporation.

Moisture in the soil is, to a small extent, derived from the atmosphere in contact with the ground (dew), in part by capillary action from water in the subsoil, and largely from direct rainfall.

The hygroscopic moisture of the air which penetrates the soil is taken up most readily by humus, to a less extent by clay, and scarcely at all by sand, as noted by Warington.† Thus sandy and gravelly soils are apt to be dry and scorched in hot weather, unless they derive moisture by capillary action from underlying clay or other substratum. He remarks that a soil containing only hygroscopic water is incapable of maintaining plant-life.

Percolation through the soil is aided by worm-holes, roots of plants, etc. It is slow when the soil or subsoil is fine-grained, as water is held in the pore spaces. This is the case with some Wealden Strata, as the Tunbridge Wells Sand, and other formations.

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* *Journ. Geol.* (Chicago), 1911, xix., pp. 676-678.

† 'Physical Properties of the Soil,' 1900, pp. 57, 63.

It is rapid where the soil is loose, coarse, or gravelly, and the substrata consist of much jointed and fissured rocks, so that the soil rapidly becomes dry. In all cases the water sinks through the pervious soils and subsoils, until arrested by clay or other impervious stratum, and the depth at which it stands is known as the water-table or plane of saturation.* This, of course, fluctuates in level, according to the rainfall and the amount drained off by springs.

The amounts of interstitial moisture that can be held in various soils and subsoils above the water-table, and those which they can hold when saturated, are of interest; but the former amount is of more importance from an agricultural point of view, the latter in questions of water-supply.

By means of capillary action moisture is retained in soils, or raised from the damp or saturated subsoil, or transmitted horizontally. The moisture thus retained on the surfaces of the particles of soil is one of the effects of the physical cause known as 'surface tension.' It has been observed that water falling on perfectly dry soil sinks slowly, while on moist soil it descends freely. In the former case, as pointed out by Mr. A. D. Hall, the percolation is hindered by the air in the soil, and by 'the want of a continuous film of wetted surfaces to lead the water down by surface tension.'

By capillary action, water may be raised in fine sand and clay loam to a distance of 4 feet daily, and in amount equal to 1 pound per square foot. Soils which have a permanent supply of water within 4 feet of the surface have advantages from capillary action, whereas crops may suffer from drought when the subsoil water is 5 feet or more below the surface.'† Drought is usually more serious to the farmer than excessive rain.

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* See H. B. W., 'The Geology of Water-Supply,' 1910, chap. iv., where the questions of Percolation, Capillarity, and Evaporation, are more fully discussed.

† R. Warington, *op. cit.*

The subsoil is here of the greatest importance, as affecting the level of the ground-water by its impervious or pervious nature and its power of absorption. In Gravel subsoils water will be held freely, in Chalk it is partly free and partly absorbed, and by Clay it is absorbed.

In peaty deposits and in alluvial silty soils capillary action readily takes place. Indeed, in soils and subsoils where the particles are fine and fairly uniform the action is most effective, but the amount of moisture that is raised naturally decreases with the distance from the plane of saturation. As pointed out by Warington, the amount of water thus retained by a soil depends on the extent of the surfaces of the particles to which the water adheres, not on the volume of the interspaces; hence, the smaller the particles, if they are not excessively fine, the greater is the amount of water held by capillary attraction. His experiments showed that 'two specimens of powdered quartz—one coarse, the other very fine—held, when fully saturated, more than 40 per cent. of their volume of water; but, when drained, the coarse quartz retained only 7 per cent., and the very fine quartz 44·6 per cent., of water. The latter lost, in fact, no water by drainage.' Coarse sand and gravel thus retain comparatively little interstitial moisture, while clay holds moisture by reason of its fine particles, although in it capillary action takes place slowly.

The amount of water that can be held by soils and subsoils when saturated depends on the size and shape of the particles and stones (their mean diameter being termed the effective size), and on the consequent pore-spaces. Here, again, we cannot do better than quote from Warington, who states that, 'if a soil consisted of spherical particles all of the same size, the empty spaces between these particles would amount to about 47 per cent. of the volume with the loosest packing, and to nearly 26 per cent. with the closest packing. The total empty space would be the same, whatever the size of the particles. If the interspaces with the closest packing were occupied by another set of smaller spheres, they would be reduced to 6·7 per cent. of the volume. If this process was again repeated, they would become 1·7 per cent. With loose packing the proportion of interspace would, in all cases, be much larger.' Thus coarse sand and fine clay, if composed of uniform particles packed in the same way, would have an equal maximum capacity for air and water.

In many subsoils the ingredients are of various sizes and irregular shapes, as in a mixture of gravel and sand, or, in Boulder Clay, with a consequent reduction of pore-space. In many loams, clays, and marls, as well as sands, the materials are fairly uniform.

With regard to the theoretical estimates of pore spaces derived from different modes of the packing of uniform particles, Mr. A. D. Hall states that 'a soil *in situ* generally possesses a pore space larger than the proportions indicated above; various causes, such as the stirring due to cultivation, the decay of vegetation, etc., leave definite cavities in the soil.' So, also, the capacity of a soil when completely saturated 'will, in fact, be the pore space, together with whatever water the material of the particles can imbibe without causing any swelling.'

The same remarks would apply to subsoils and substrata.

Clay and peat swell when saturated, so that the ground may rise and sink again during dry weather. Thus, according to Hilgard, soil on bog-land may increase 30 per cent. in volume when saturated. On the other hand, wet sand diminishes but little in volume when dried.

As a rule, it is admitted that the more water a soil or subsoil absorbs, the longer will it be retained.

Warington (1900, p. 67) quotes the following table, after Meister and Schwarz:

WATER IN FULLY SATURATED SOILS.

Soils.	Volume of Water per 100 of Soil.	Weight of Water—	
		Per 100 Wet Soil.	Per 100 Dry Soil.
Sandy soil	45·4	23·3	30·4
Chalk soil	49·5	28·2	39·2
Clay	50·0 to 52·7	27·8 to 30·8	38·5 to 44·5
Loam	45·1 to 60·1	24·3 to 31·2	32·2 to 45·4
Garden earth	69·0	43·4	76·8
Coarse sand	39·4	19·8	24·7
Peat subsoil	84·0	78·2	359·0

The following statistics relating to soils and substrata must be regarded as indicating in a general way only the amount of water held when the materials are saturated:

	Per Cent. by Bulk.	Gallons per Cubic Foot.
Mould or humus	65 to 90	2·6 to 5
Peat	80 to 90	—
Very fine sand	—	1·8
Ordinary quartz sand	25	—
Coarse sand	35 to 40	2 to 3
Gravel and sand	—	2
Fine loamy sand	—	2·8
Loam	50 to 60	3·8 to 4·2
Ordinary clay	up to 63	4·5
White clay	66 to 70	4·8
Chalk	33 to 50	2 to 2·5
Oolitic freestone	24	1·5
Magnesian limestone	16	1·0
Carboniferous limestone	0·7	0·04

It has been pointed out by Warington that soils of various characters evaporate equal amounts while saturated, but exhibit great differences, according to composition and texture, as they become drier. No water is liable to evaporation when 2 or 3 feet below the surface, except through processes of capillary action.

On the Rothamsted estate it has been ascertained that percolation through the soil, free from vegetation, and to depths of 5 feet, amounts to rather less than half the annual rainfall, the other portion being mostly evaporated.

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CHAPTER IX

ANALYSES: CHEMICAL AND MECHANICAL CONSTITUENTS OF SOILS, PLANT FOODS, AND BACTERIA

In dealing briefly with the above subjects, we enter more particularly into the provinces of the agricultural chemist, physicist, and botanist, upon whose researches our information wholly depends.

Chemical analyses are important in determining the composition of the fine organic and inorganic materials of soils, because they not only indicate the total amount of plant food, but also the presence or absence of particular foods and of injurious substances. Chemical analysis, however, does not prove that the mineral ingredients are 'active' or available as plant food, nor does it as a rule take note of the composition of the coarser ingredients.

Mechanical or physical analyses of soils are important in determining the nature, size, and proportion of the mineral ingredients, upon which the texture of the soil and the available plant food largely depend.

Some aid to the determination of the amount of available nutriment may be given by means of solutions which indicate the percentage of phosphoric acid and potash that can readily be dissolved from the soil.* Analyses of plants or of their ashes are important in affording evidence of the ingredients taken from the soil.

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* See Somerville, 1912, p. 104.

Apart from the objects thus stated, analyses supply data of great value in determining the kind of manure suitable to the chemical and physical state of the soil, and to the requirements of the crops.

Analyses of green plants prove the following ingredients, and all, excepting hydrogen and nitrogen, occur (in combination with various constituents) in the ashes:

Essential Ingredients.

Carbon
Hydrogen
Nitrogen
Oxygen
Calcium
Iron
Magnesium
Phosphorus
Potassium
Sulphur

Ingredients always Present, but not Proved to be Essential.

Chlorine
Silicon
Sodium

Occasional Ingredients.

Aluminium
Bromine
Iodine
Lithium
Copper
Manganese
Zinc
Lead

The following particulars relating to plant constituents are given mainly on the authority of Professor J. Percival (1902):

Carbon.—40 or 50 per cent. of dry matter: obtained chiefly as carbon dioxide or carbonic acid from the atmosphere through leaves, and partly from organic compounds (humus) and carbonates in the soil.

Hydrogen.—5 to 6 per cent. of dry matter: obtained from the water of soil and subsoil by rootlets; and, as noted by Warington, water is taken up to some extent from dew or rain through leaves after severe drought, and when the plant is in a wilted condition.

Nitrogen.—1¾ to 7 per cent. of dry matter: taken from soil chiefly in the form of nitrates. Leguminous plants derive free nitrogen from the atmosphere. Nitric acid is also brought by rain from the atmosphere of manufacturing towns. Nitrogen is rare as a rock ingredient.

Oxygen.—35 to 45 per cent. in dry matter: absorbed from air in soil, and obtained from carbonates, nitrates, sulphates, and phosphates in soil.

Calcium.—Derived from soil in the form of nitrate, phosphate, and sulphate. Present also in the form of carbonate.

Iron.—From soil, where it occurs in the form of ferric oxide, etc.; the green colouring matter of plants, or chlorophyll, appears to be dependent on the presence of iron salts.

Magnesium.—From carbonate and sulphate in soil.

Phosphorus.—From calcium and potassium phosphates in soil.

Potassium.—From carbonate, chloride, nitrate, phosphate, and sulphate in soil.

Sulphur.—From sulphates in soil.

Chlorine.—From chlorides in soil.

Silicon.—From soluble silicates in soil; present in stems and leaves of barley, oats, wheat, and grasses.

Sodium.—From chloride in soil, etc.; present in plants of salt marshes; also obtained from carbonate, nitrate, silicate, and sulphate.

It is reckoned that living plants contain more than one-half of their weight—rarely less than three-quarters—of water. The amount of water actually transpired through a crop has been roughly estimated at about 300 pounds for every pound of dry matter produced; so that 2 tons of dry matter per acre would require at least 600 tons of water (6 inches of rain), apart from loss by evaporation, percolation, and run-off.*

The need of supplies of moisture in the subsoil is indicated by the fact that plants for a time may part with more water to the air than the land receives as rain.†

Plant foods are obtained from the mineral matters held in solution in the soil-water, and to a further extent also in the water or moisture in the subsoil. The water is taken up by the root-fibres or root-hairs, being absorbed by a process of 'osmosis,' defined by Professor Percival as 'the diffusion or passage of liquids and solutions through membranes in which no visible openings are present.' The uprising of water or sap through the roots is caused mainly by the evaporation or transpiration of water vapour from the leaves.

The roots have the double function of maintaining the plant in position and of supplying the necessary food; hence, the depth of soil and nature of the subsoil are all important. It has been pointed out that most agricultural plants, and most plants in temperate climates, have roots adapted almost exclusively to the surface soil. Nevertheless, roots of rye, beans, and peas, sometimes extend to depths of 4 feet. In fertile soils the roots are short, with many branches and root-fibres, so that they occupy much ground; in poor sandy soils they are long and slender.

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* *Nature*, August 6, 1908.

† Somerville, 1912, p. 28.

The expansion and contraction of clay during wet and dry weather are apt to cause injury to roots and rootlets through the induration and rupture by fissures. Nevertheless, clay that is apparently dry often contains enough moisture to nourish plants, especially at some depth. Where the subsoil or substratum is hard rock not much shattered, the roots must spread laterally in the soil; where fissures occur in the rock, the roots then find their way to a farther depth, and sometimes spread laterally in a lower stratum of soft material. Soil with humus may be washed down into crevices, and thus help to supply plant food at a considerable depth.

In 1838 the Agricultural Society awarded a prize to the Rev. W. L. Rham, Vicar of Winkfield, Berks, for 'An Essay on the Simplest and Easiest Mode of Analyzing Soils.'* Observing that, while the fertility of a field is most largely influenced by 'the organic portion of the soil,' nevertheless, the fertility 'depends more on the texture and division of the component parts of the soil, and its consequent affinity to water, than on the absolute proportions of the simple earths of which it is composed'; he concluded 'that the chief object in a practical agricultural analysis of a soil is to ascertain the relative size of the particles of which it is composed, their chemical nature, their affinity to moisture, and the quantity of organic matter intimately blended with the earths.' He noted that the power of retaining moisture in the pores was greater as the particles of the soil were finer. It was greatest in humus, next in clay, and least in siliceous sand, while loams with humus absorb more water than purer earths.

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* *Journ. Roy. Agric. Soc.*, 1840, i., p. 46.

To encourage farmers unacquainted with chemistry and mineralogy to make useful agricultural analyses, he gave instructions with regard to tests for estimating the amount of water absorbed; to estimates of specific gravity as indicative of light and heavy soils; to a method of sifting soils through metallic sieves of different fineness to ascertain sizes of particles; and, finally, to means of determining amounts of sand, clay, humus, and carbonate of lime.†

Thus, many years ago, the importance of mechanical as well as of chemical analyses of soils was advocated. (See also p. 26.) Here we may give some examples published by Mr. A. D. Hall in his work on Rothamsted (1905).

ANALYSES OF UNMANURED WHEAT SOILS AT BROADBALK, ROTHAMSTED, MADE BY DR. B. DYER IN 1893.

Soil dried at 100° C.	First 9 Inches.	Second 9 Inches.	Third 9 Inches.
	Per Cent.	Per Cent.	Per Cent.
Loss on ignition	4·20	4·61	5·11
Containing carbon ...	0·888	0·565	0·483
Containing nitrogen ...	0·099	0·073	0·065
Soda*	0·058	0·090	0·106
Potash*	0·274	0·446	0·618
Potash, soluble in 1 per cent. citric acid	0·0032	0·0060	0·0072
Magnesia*	0·360	0·420	0·400
Lime*	2·486	0.460	0·538

* Determined in the solution obtained by treating the ignited soil with strong hydrochloric acid.

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† In the same volume in which the above-mentioned essay was published there was inserted an equally important article 'On the Physical Properties of Soil, and on the Means of Investigating them,' by Professor Schübler, of Tübingen.

ANALYSES OF UNMANURED WHEAT SOILS (*Continued*).

Soil dried at 100° C.	First 9 Inches.	Second 9 Inches.	Third 9 Inches.
	Per Cent.	Per Cent.	Per Cent.
Alumina*	4·486	7·407	11·623
Oxide of iron*	3·400	5·200	7·200
Phosphoric acid*	0·114	0·113	0·097
Phosphoric acid, soluble in 1 per cent. citric acid ...	0·0078	0·0045	0·0025
Sulphuric acid†	0·048	0·041	0·038
Carbonic acid†	1·300	0·050	0·100
Undissolved matter* ...	83·700	81·480	73·220

* Determined in the solution obtained by treating the ignited soil with strong hydrochloric acid. † Determined in the unignited soil.

Mr. Hall remarks (p. 27) that 'the most notable feature in the Rothamsted soil is the amount of calcium carbonate in the surface layer; analyses of the earliest samples available (1856) show more than 5 per cent. in the surface soil of Broadbalk field. This amount is always being reduced by the action of the rain washing it away as calcium bicarbonate.' There is also much loss elsewhere due to the application of manure. In Mr. Hall's opinion, the original soil was almost devoid of calcium carbonate, and its presence is due to the chalking of the land in old times.

The diameter of soil particles given by Wollny has been adopted by Warington (1900) and others, as follows:

	Diameter of Particles in Millimetres (1 = about $\frac{1}{25}$ inch).
Stones	over 10
Coarse gravel	5 to 10
Medium gravel	2 to 5
Fine gravel	1 to 2
Coarse sand	0·5 to 1
Medium sand	0·25 to 0·5
Fine sand	0·1 to 0·25
Coarse silt	0·05 to 0·1
Medium silt	0·025 to 0·05
Fine silt	0·005 to 0·025
Clay	0·0001 to 0·005

The terms indicate size, apart from the nature of the constituents, some, like quartz, being impervious, and others, derived from certain limestones and sandstones, being pervious.

The determination of the size of particles affords a means of estimating the surface areas to which the water may adhere, so that the proportion of the finer particles is of great importance. (See p. 96.)

The following is an example of the mechanical analyses of Rothamsted soils:*

Soils.	First 9 Inches.			Second 9 Inches.	Third 9 Inches.
	Broad-balk.	Hoos Field.	Barn Field.	Broad-balk.	Broad-balk.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Fine gravel, 3 to 1 mm. ...	1·9	2·0	3·1	1·7	0·5
Coarse sand, 1 to 0·2 mm.	6·2	6·8	5·9	4·3	2·5
Fine sand, 0·2 to 0·04 mm.	21·4	19·5	19·7	15·8	13·2
Coarse silt, 0·04 to 0·01 mm.	32·5	28·9	26·0	24·0	18·0
Fine silt, 0·01 to 0·002 mm.	13·8	15·5	13·1	16·7	13·8
Clay, less than 0·002 mm.	17·6	18·8	25·6	28·7	40·0
Carbonate of lime, loss on solution, etc.	4·2	—	3·7	—	—
Hygroscopic moisture ...	2·2	2·5	2·8	3·8	5·3

Mr. Hall remarks (1905, p. 25): 'Notwithstanding the irregularity of the subsoil, the agricultural character of the soil is fairly uniform all over the estate; some fields work rather more heavily than others, and the proportion of stones lying on the surface varies somewhat, but these differences are comparatively unimportant. The soil passes into the subsoil without any sharp line of distinction, and the distribution of flints in the subsoil is very irregular, while the solid chalk is reached at depths varying between 8 and 12 feet.' The soil in general consists 'of a heavy loam containing little coarse sand or grit. but a considerable amount of fine sand and silt, and a large body of clay. In consequence, the soil has to be worked with care, becoming very sticky, and drying to impracticable clods if moved when wet. It "runs together" if heavy rain falls after a tilth has been established, and then dries with a hard, unkindly surface, these difficulties being much exaggerated on the plots which have been farmed for a long time without any supply of organic matter in the manures.' (See also p. 34.)

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* A. D. Hall (1905, p. 26). For an account of modern methods, see Hall, 'The Mechanical Analysis of Soils,' *Trans. Chem. Soc.*, 1904, lxxxv., p. 950. The designation 'klay' was then suggested for material having a diameter of less than 0·002 millimetres, the clay in the above table.

BACTERIA.

The fertility of soils is greatly influenced by minute forms of life known as bacteria, and certain fungi which occur in humus and in decaying plants and animals, as well as in the air of soils. Flourishing under warm and moist conditions, though injuriously affected by great heat, sunlight, and dryness, these microbes or micro-organisms are the means of converting nitrogen into ammonia, and finally into nitric acid, which, uniting generally with lime, and also with potash and magnesia, forms the soluble nitrates that are assimilated as foods by most plants.*

For a fuller account of the two processes of nitrification and denitrification, the reader may be referred to Mr. Hall's 'Book of the Rothamsted Experiments.' It needs only to be added here that the organisms to which the former process is due are present in enormous numbers in all cultivated soils, and down to depths of 3 or more feet according to the porosity and moisture of soil and subsoil, but mostly 'in the first 9 inches, which gets stirred about and aerated by the plough.' Denitrification is the reverse process, by which nitrates are destroyed and nitrogen gas set free. This is due to another set of organisms, which have the power of changing nitric acid into nitrous acid and ammonia, and ultimately nitrogen, and in a wide sense it is a process always going on in the soil.*

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* See T. Goodey, *Proc. Roy. Soc.*, 1911, 84B, p. 165.

Leguminous plants (clover, peas, etc.) possess the power of absorbing or 'fixing' atmospheric nitrogen by the agency of bacteria living in the nodules on their roots; hence, as remarked by Professor Percival, leguminous crops can be raised on soils devoid of nitrogen, if nodule bacteria are present and the soil is otherwise suitable.†

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* For an introduction to the chemistry of the subject, see Dr. G. J. Fowler, 'Bacteriological and Enzyme Chemistry,' 1911, pp. 217, 228, and chap. xvi.

† A. D. Hall, 1905; Percival, 1902.

CHAPTER X

THE FERTILITY AND BARRENNESS OF LANDS

SOILS may be grouped into those naturally fertile, naturally sterile, and those that may be rendered fertile by cultivation. There is every gradation between fertile and sterile soils, dependent on the nature, aeration, and depth of soil, and the pervious or impervious character of the subsoil; on climatic conditions, physical features, and aspect. Wherefore soils of similar character may be fertile in one region and barren in another.

Fertility, as previously indicated (p. 100), depends in part on the 'active' mineral ingredients that supply plant food and are held in solution in soil-water—notably on potash, lime, and phosphoric acid. Where the mineral ingredients may be present, but in a 'dormant' condition, not readily soluble, the soil may be infertile. Fertility depends, also, on the amount of humus.

Naturally fertile soils are in the main the dark grey and black earthy soils that owe their tint to the humus, the red and brown loamy soils, and some volcanic ashy soils.

Naturally sterile or barren soils are often those of pale yellow and whitish clay, the latter comparatively pure; the soils of clean siliceous sand, as in some beds of the Bagshot Sand, the white sands of the Lower Greensand; and those on pure limestone or hard limestone, where, in fact, the soil is thin and the ground more or less rocky.

The same remarks would apply in many cases to ground where slates, quartzites, and granites, are developed.

The classification of soils (noted p. 78) into clayey, loamy, etc., is based to a large extent on general texture.

The *Heavy Soils* include the clays and loamy clays or clay loams, sometimes termed 'hazelly loam,' and some of the marls; and these are in various degrees described as stiff, strong and tenacious, stubborn and intractable, cold, retentive and cohesive, sticky and caking, but generally as heavy to work. Some clays or shales break into more or less rectangular or cuboidal fragments, when they are known as dice or dicey. Marls often have a cuboidal structure.

The cracks which occur in clay lands in very dry seasons often extend 4 feet and more in depth. (See p. 103, also Fig. 10.) When a thin gravelly soil occurs, pebbles are liable to be carried into the cracks, and afterwards incorporated with the clay. Where ground is formed of 3 or 4 feet of clay on limestone, as in the case of the Great Oolite Clay on the Great Oolite Limestone of Bedfordshire, the surface may be seen to be so cracked and fissured that much rain is conducted underground into the jointed limestones, where the rocks are weathered into miniature caverns. Similar features may be seen in other formations, such as the Lower Lias. (See Fig. 10.) In process of time clay is carried downwards so as to fill some of the fissures in the Great Oolite Limestone.

Horizontal cracks occur sometimes in dry clays, as in the case of the Forest Marble.

During heavy rain, as remarked by Warington, the finer particles of a tenacious clay soil may be washed away, so that in course of time the soil may contain a larger proportion of coarser particles than the subsoil.

On well-drained clay-land the effects of tillage are to increase the depth of soil, improve and lighten its texture into a more or less friable loam, so that it does not become so hard in dry weather, while the aeration promotes the oxidation of the iron salts. (See p. 112.)

In some cases a kind of clay-pan or indurated soil, which arrests percolation, is caused by the pressure during the process of ploughing. This may be from 5 to 8 inches below the surface, and, as remarked by Warington, it may require to be broken up by subsoil ploughing.

Soft clay pasture-lands, which become full of holes and puddles through the trampling of horses and cattle, are termed 'poachy,' and such land is noticeable on many tracts of the Fuller's Earth Clay.

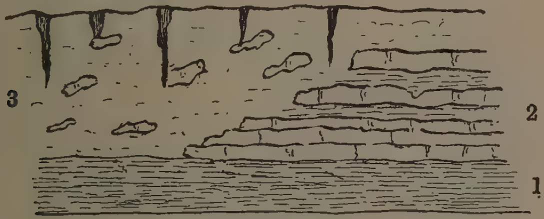

FIG. 10.—SECTION ALONG RAILWAY NEAR PENARTH, GLAMORGANSHIRE.

3, Stiff clay soil, with wide cracks extending to depth of 4 feet.
2, Lower Lias limestones which have become weathered, separated into nodular masses, decalcified, and water-worn, about 7 feet.
1, Lower Lias shale, about $3\frac{1}{2}$ feet.

At an excursion of the Essex Field Club in June, 1912, attention was drawn by Mr. L. F. Newman to a part of 'derelict Essex,' formerly cultivated land, between Langley and Chiswick Hall, south of Chrishall. The ground is formed of chalky Boulder Clay, which is decalcified more or less, so as to leave a noticeable accumulation of stony clay loam that appears to be infertile. The land was allowed to revert to waste, about thirty years ago, at a time of agricultural depression. There are also tracts of loam or brickearth over Boulder Clay, as shown here and there on the Geological Survey map; and hard yellow loam is intercalated in Boulder Clay at Wenden, as observed by W. H. Penning.* (See also p. 233.) Similar lands now derelict were pointed out to the writer near Halstead, in Essex, by Mr. T. S. Dymond.

The *Medium and Mild Soils*, the more generally fertile, include the loams, the sandy, gravelly, peaty, and calcareous loams, and stonebrash. The loams in general yield rich, open, and free-working soils, and a sandy calcareous loam with humus, such as occurs over the Contorted Drift of North-East Norfolk, is of great fertility. Good deep loams are often spoken of as 'turnip soils. Some of the lighter marls yield soft and mellow soils, locally known as 'malm,' while some of the brashy soils have a rather sticky clay matrix.

The *Light Soils* include the sands, loamy sands, and gravels; loose, free, and pervious soils, that are light to work. The calcareous and ferruginous sands are fertile, or rich and 'kindly,' as they are sometimes called. So also the gravels with sandy matrix, more or less calcareous and ferruginous, are likewise productive, and are spoken of as 'sharp' or 'quick' soils when the growth of crops is rapid.

On the other hand, there are dead and sleepy sands, such as the purely siliceous sands, some gravels, also limestones, that are poor and hungry. They retain little moisture, since, owing to their loose nature, humus is washed out, and the effects of manure are minimized by the rapid percolation, especially where the soil is thin.

Agricultural operations through tillage, processes of ridging, draining, and manuring, tend to render pervious the more clayey soils, and to increase capillarity, so that more moisture is retained. In this way, aided by various weathering agents in the pulverization of clods, is produced the fine tilth, or open, mellow, and friable condition of a soil. From such a soil less evaporation takes place than from one liable to cake, but the tilth should not be too fine. Drainage by carrying off surface or subsoil water must also tend to diminish the amount that would have been evaporated. 'Fresh soil' has been described as that which yields only traces of moisture when squeezed in the hand.

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* 'Geology of North-West Essex,' *Geol. Survey*, 1878, p. 38.

James Caird, in 1878, remarked that the maximum of fertility is indicated by 'a rich pasture capable of fattening an ox and two sheep on an acre,' and he instanced the Pawlet Hams in Somerset and the marsh-lands of Sussex and Kent as examples. 'The minimum of fertility may be exemplified by a bleak mountain pasture, where ten acres will barely maintain a small sheep.'*

Lands will be generally infertile if the ground is waterlogged, although rice grows in swampy lands and flooded fields; where the soils contain injurious substances in metalliferous areas, such as copper-ores; where the soils have an excess of nitrates or even of humus, as in deep bogs or peat-lands; or where the lands are infested with noxious forms of animal and plant life. In Western Australia, for example, lands on which poisonous plants flourish are, at any rate, undesirable. The barren lands in arid or desert regions, such as the Sahara, or, again, in frozen regions, need only a passing mention.

Many areas of so-called waste or barren land in England have been rendered fertile by cultivation. Thus, large sandy tracts, formerly warrens in West Norfolk and on Lincoln Heath, have been turned into fertile arable lands by the application of marl. (See p. 131.)

On the borders of Norfolk and Suffolk, near Thetford and Brandon, in the parishes of Santon and Santon Downham (or Downham Arenarum), the land, as may be judged from the names, has been liable to sandstorms, which in the earlier half of the seventeenth century ruined a number of meadows and pastures. The ground, which came to be regarded as the poorest in the district, was ultimately improved by the application of marl. It was remarked by William Smith that on these shifting sands of West Norfolk the 'soils cannot be managed without sheep,' or the advantage of sheep-dressing.

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* *Journ. Roy. Agric. Soc.*, 1878, 2nd series, xiv., p. 292.

Boggy land, again, may be drained, and rendered fertile by the application of marl. (See p. 131.)

Land of a naturally sterile character that has been brought under cultivation will return to its former barren condition if worn out or exhausted by want of manure or otherwise neglected. Large areas in the United States and elsewhere have been exhausted under cultivation and abandoned, with, in some cases, disastrous results. Hence, as described by Professor W. H. Hobbs, when the land, bared of vegetation by agricultural operations or the cutting of timber, has been abandoned, 'the surface is opened in gullies by the first hard rain, and the [once] fertile layer of soil is carried from the slopes and distributed with the coarser mantle upon the bottom lands. Thus, the face of the country is completely transformed from fertile hills into the most desolate of deserts, where no spear of grass is to be seen and no animal food to be obtained. The soil once washed away is not again renewed, for the continuation of the gullying process now effectively prevents its accumulation.'* Such areas form portions of the 'Bad Lands' of Western America—rough, bare, and hilly country, much broken up by deep ravines, where there is little or no vegetation except grassy tracts in the valleys. (See Plate III., Fig. ii.)

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* 'Earth Features and their Meaning,' 1912, p. 156.

Referring to the loss of soil and gullying of fields by rain on steep slopes, Mr. S. Weidman recommends that such tracts should be kept as woodland; but if already cleared for arable cultivation, 'crops should not be planted oftener than once in three or four years, and the slopes should be allowed to remain in hay-meadows or pasture the remainder of the time.'*

The rapid recovery of fertile tracts when devastated by volcanic eruptions has often been noted. In Guatemala, after a great eruption of Santa Maria in 1902, described by Mr. W. S. Ascoli as the first on record, a tract of land that had been the richest coffee zone in the country became an arid plain of volcanic débris. In course of time much of the material was washed away by rains, and some estates were restored even with benefit, inasmuch as 'the principal constituent of the rich soil necessary for the cultivation of coffee is this very débris,' and it was noted that 'the class of coffee has improved throughout the district since the disaster.'†

In describing the eruptions of the Soufriére in St. Vincent in 1902, Dr. Tempest Anderson and Dr. J. S. Flett remarked on the rapidity with which the volcanic rocks decompose. In consequence, there is a great depth of soft earthy material, largely due to the weathering of tuffs or ash-beds, and forming rich soils. The best land is occupied by arrowroot and sugar estates, the latter on the alluvial ground of the valleys. The volcanic ashes consist of—silica, 52 to 57 per cent.; alumina, 17 to 19 per cent.; lime, 6 to 9 per cent.; iron oxides, and small quantities of magnesia, potash, soda, phosphoric acid, etc.‡

The principal alluvial valleys and plains of the world, which have become noted for their fertility or other natural characteristics, may here find a brief mention. The Nile Valley, fertilized by flood-waters which deposit fine mud over the lowlands and the delta, yields some of the richest lands on the face of the earth.

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* Wisconsin, *Geol. Survey*, 1911, Bulletin xxiii., p. 80.

† *Journ. Manchester Geograph. Soc.*, 1908, xxiv., p. 97.

‡ *Phil. Trans.*, A., 1903, vol. cc., p. 353; and Flett, *ibid.*, 1908, vol. ccviii., p. 305.

The great plains of South America include the Pampas in the drainage area of the La Plata (Uruguay, Parana, and Paraguay), in Southern Brazil, and the Argentine Republic. These comprise extensive areas of loam and loess, sandy and clayey marl, in part Glacial Drift, in part alluvial flood plains; with flat or undulating tracts, at different elevations, of grass-land, almost devoid of trees, affording pasture for cattle and sheep and fertile arable lands.

Farther north are the Selvas, bordering the Amazon in Brazil—primeval forests, with 'the densest vegetation on the globe'; and still farther north, in Venezuela, are Savannas or 'Llanos, with tall grasses and isolated trees, many of them palms.' The Llanos rise to elevations of 800 feet, and slope downwards to the Orinoco River. They are composed of gravels, sands, clays, and ferruginous breccias, resulting from the denudation of the mountains, and are cut by the rivers into tracts called 'Mesas,' which are dry, while the valleys are humid.*

In North America the prairies, or lowland plains, consist of level or undulating ground, with deep and fertile soils derived largely from Glacial Drifts (Boulder Clay, loam or loess, gravel, and sand). Coarse grass without trees characterized the lands until taken into cultivation, when maize or Indian corn, wheat and other crops, and excellent grazing grounds, as well as plantations of trees, have transformed the aspect of the country.

Corresponding to some extent in character are the Steppes of South-Eastern Russia, South-Western Siberia,

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* A. J. Herbertson and W. Sievers in 'International Geography,' 3rd edit., pp. 820, 885.

Turkestan, etc. These are more or less elevated plains with some hills, characterized by dry and wet seasons, and by grasses and other plants able to survive the droughts of summer, but with few trees, except in occasional tracts. While portions are desert with saline areas, large parts are fertile. The Steppe conditions, indeed, are considered especially favourable to wheat and maize, not only in these Eurasian regions, but in North America and in the Argentine Republic.

In regions farther north in Europe and Siberia are the Tundras—undulating plains with occasional rocky eminences—where the ground is frozen perpetually to some depths, and only the surface is thawed during the short summer. There the vegetation is limited to lichens, mosses, and some shrubs. The barren lands of North America are of somewhat similar character. They extend beyond the limit of trees, such as the black and white spruce and American larch, which grow in the sub-Arctic forests of Canada, and become more and more stunted as they approach the Arctic regions.*

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* J. B. Tyrrell in 'International Geography,' 3rd edit., p. 682.

CHAPTER XI

DRAINAGE AND IRRIGATION—WATER-MEADOWS

ALL soils and subsoils are liable to be dry or wet according to the depth at which an impervious stratum occurs. This holds up the ground or subsoil water, the depth of which from the surface varies according to the thickness of the pervious strata and the amount of rainfall.

The term 'underground water' applies to all water beneath the surface; but in many cases this is not derived by direct downward percolation of rain, as is the case with ground-water, from which it is separated by a bed of clay or other impervious stratum.

The amount of water held in the land as ground-water depends, of course, on the geological structure. Where pervious strata rest on an inclined foundation of clay or shale, the ground-water may be rapidly thrown out in the direction of the dip along one side of a hill; where the strata are approximately horizontal, and in hilly tracts where gravel and sand or other pervious strata rest on clay or shale, water would not so rapidly escape; and often the surface of the clay is irregular, with hollows holding underground pools of water. Here the depth to the ground-water or water-table is of most consequence, and it may generally be ascertained from the level at which springs break out along the slopes. They may issue from joints in hard rocks, or from fissures caused by faults. In some cases there are definite outlets, in other cases water issues feebly in the form of seepage along a general level where the strata are fairly flat, as, for example, on the Middle Lias slopes of Pennard Hill in Somerset.

Hilly clay-lands that are impervious, and areas that have a great thickness of pervious strata of gravel and sand or of limestone, like the Chalk Downs (except where covered by Clay-with-flints), are, as a rule, naturally drained by 'run-off' in some cases, by percolation in others. On the clay hills, and on hilly ground formed by fine silty sand, much rain would run off grass; but it would descend through shallow soil in arable land, and flow over any stiff or impervious subsoil, causing a certain amount of downwash of soil.

Thus, some grounds, by reason of their geological structure and slopes, may require no artificial drainage. Some, indeed, have a deficiency of subsoil water, while, on other lands, there is a superabundance of water at times from direct rainfall and the outbreak of springs.

Low-lying lands liable to be flooded by overflow of rivers and by excessive rains require special treatment by embankments and the aid of pumping machinery. Thus, tracts like the Fenland and many parts of Central Ireland present difficulties.

Higher lands require drainage to regulate the flow of water after rains. If in the form of seepage, whether from flat or inclined strata, a catch-drain along the hill-side may be needed.

Drainage is especially required on level or gently undulating districts of clay and heavy loam, and where there is no great depth of pervious subsoil, as water is apt to accumulate on the surface or to saturate the subsoil. Water-logged soils and subsoils are injurious to almost all plants, and draining not only gets rid of water liable to become stagnant, but also aerates the soil, thereby raising its temperature and improving the tilth. (See p. 113.)

Drainage may be effected by open channels, known as 'furrows,' 'cuts,' or 'grips' (surface draining), or by covered channels (under draining).* Surface draining may be adopted in the case of a definite spring which issues on a slope, on some flat lands, on hill-pastures, and in woodlands. The channels may be from 1 foot to 4 feet deep, and lined with stones. Peaty tracts, when of considerable extent, usually require deep drainage. Peat is highly absorbent, but not very pervious.

In underground drains tiles or pipes are mostly used, but sometimes the trenches are lined with pebbles or broken rock. Where the drainage-water comes from limestone tracts, the pipe-drains sometimes become encrusted with carbonate of lime.

The depth of the drains, their position, and inclination, must depend on the thickness of soil and subsoil, the slope of the land, and the level of ground-water. Expert engineering advice is, of course, requisite in laying out drains, but much aid will be afforded by a 6-inch geological map of the subsoils, with records of the depths of soil. Covered drains are usually adopted in ordinary meadow, pasture, and arable lands.

Over the great clay tracts of the New Red Marl, the Lias Clays, the Oxford Clay, etc., where the soil is thin, drains about 2½ feet deep are appropriate; where there is more porous soil, the drains are made deeper and farther apart.

In loams the drains are usually made 3 to 3 feet 3 inches deep, and in lighter soils from 3½ to 4½ feet, and farther apart. The distance apart of the drains may vary from about 18 to 24 feet. In all cases drains must be below the level of deep ploughing, but not so deep as to interfere with capillary action.

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* See H. H. Smith, 1908, p. 219, etc.

Drains, if too deep, may leave the soil too dry in times when there is little rain, but in pervious strata of sand and gravel of no great thickness drainage channels may be cut into underlying impervious clay.

Drains, where possible, are constructed to have a fall of about 1 in 300 to 330 on lower grounds, and about 1 in 200 on higher, and along the slopes they are carried in a direction oblique to the natural run of water.

Attention has been drawn elsewhere (p. 214) to the occurrence of irregular natural furrows in some of the strata, due in certain cases to subterranean erosion by streams, in others to surface disturbances. Trimmer remarked on the desirability of giving attention to the direction of these furrows in schemes for draining land, and quoted Godwin-Austen 'to the effect that occupiers of soils near Guildford, resting upon a subsoil of clay so furrowed, had found that drains across the ridges and furrows dried a much larger area than drains parallel to them.' *

Such a system was adopted on the Keythorpe estate east of Goadby, and about seven and a half miles north-north-east of Market Harborough, in Leicestershire, the position of the drains being determined after trial-holes had been made. The substrata, as described by Trimmer, and as subsequently shown on the Geological Survey Map (New Series, Sheet 156), comprised: Gravel, made up of flints and much limestone, 12 to 15 feet thick; Boulder Clay, with much Chalk and flint; Upper Lias Clay; and Middle Lias (Marlstone), etc. It was on the higher grounds that particular drainage was required—where the Boulder Clay and Lias Clay occurred at the surface, and were trenched naturally by hollows filled with porous loamy warp-drift. Although the furrows were found in most cases to run in the direction of the fall of the ground,

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* *Journ. Roy. Agric. Soc.*, 1853, xiv., p. 96.

drains were carried down through the clay ridges or 'clay banks' to the bottom water in the hollows to depths of 3½ to 6 feet, and the results proved to be satisfactory.

In 1904 the Duke of Bedford founded an experimental station for the study of fruit-culture in a field of twenty acres close to Ridgmont Railway Station, north-east of Woburn, in Bedfordshire. The soil there consists of 9 or 10 inches of sandy loam on Oxford Clay. Owing to the fine state of the sand, the land 'had a bad reputation amongst the farmers, the water often standing on it in places for weeks together in a wet season.' The ground has since been improved by tillage, 'and though a comparatively small amount of rain still renders it unworkable, yet in dry weather it presents as good a tilth as could be desired.' The greater part is intersected 'with tile drains 30 feet apart, but as these are sunk well into the stiff clay 3 feet below the surface, they have practically no effect on the surface drainage.'* Reference has previously been made to some of the very fine Wealden Sands, which hold up surface-water in rainy weather.

Some clay tracts have been drained by means of dumb wells. These have been sunk through the Estuarine Clays above the Lincolnshire Limestone, through the Upper Lias above the Marlstone, and in other formations where the clay coverings are not of great thickness. Topley has noted that the Kentish Rag, near Sevenoaks, was used for draining by means of wells, sometimes filled with stones. The shafts sunk to obtain chalk in Hertfordshire, when abandoned, have been used sometimes for drainage. (See p. 165.)

Railway cuttings often have great and not always beneficial influence on draining adjacent lands.

The wholesome effects of the drainage of swamps, marshy tracts, and stagnant pools in tropical countries, with a view to the suppression of the mosquitoes that spread malaria, are well known, and a somewhat analogous case nearer home is found in the disappearance of ague which has followed on the drainage of the Fen district.

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* 'First Report on Woburn Experimental Fruit Farm,' by the Duke of Bedford and S. U. Pickering, 1897.

IRRIGATION.

Many extensive arid tracts where the soil, dry and pervious, is naturally rich, but the rainfall is small and uncertain, are found in the central plains of India, in Egypt, South Africa, in California, Arizona, Nevada, Utah, New Mexico, in parts of Canada and Australia, and in such regions recourse must be had to irrigation on a large scale.

In connection with such artificial irrigation, Professor F. H. King (1899, p. 29) has observed that 'little or no care is taken to avoid exposing the subsoil or covering, even deeply, the surface layer,' in the process of levelling ground for the easier distribution of water, as earth 'from depths of 30 feet may be quite as productive, if not more so, than that which has been long exposed to the air.'

The fact is that both soil and subsoil are, as a rule, incoherent and liable to be wind-drifted, and they generally contain a considerable amount of lime, not having been much decalcified by the action of rain-water holding carbonic acid.

Irrigation works have been necessary in various parts of Canada, especially in the fruit districts of Columbia, where the rainfall ranges only from 9 to 10 inches, and sometimes falls to 2 inches. In the Calgary district a reservoir has been constructed, three miles long by half a mile wide, with a depth of 40 feet.* In New South Wales a great scheme has been undertaken at Burrenjuck to provide works for the irrigation of $1\frac{1}{4}$ million acres by means of a reservoir forty-three miles long and 200 feet deep, and a capacity of 32,000 million cubic feet of water.*

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* *Nature*, August 10, 1911, p. 192.

Sub-irrigation is a modification of sub-surface irrigation, and the processes adopted in Colorado are thus explained: 'In sub-surface irrigation the water is carried in underground tile or perforated pipe directly beneath the roots of the plant to be irrigated, as, for instance, beneath a row of fruit-trees.' † The practice, however, when long continued, is apt to render the soil alkaline, because, as the water is drawn to the surface and evaporated, it there leaves the salts, leached elsewhere from the soil and subsoil.

While in dry regions where the annual rainfall amounts to about 10 inches, it has been necessary to resort to irrigation, in other countries where the rainfall is from 15 to 20 inches, a system known as 'dry-farming' (without irrigation) has been successfully introduced, as in the drier parts of South Africa, Canada, and the United States.

In a favourable loamy soil and subsoil of clay-loam or clay, deep ploughing is found to retain the water near the surface and prevent or check evaporation, the subsoil being of a nature to arrest downward percolation, while means are taken to keep the surface soil loose and dry.‡ Cultivation is not always carried on every year, but in alternate years in certain areas, as in Wyoming, where the rainfall sometimes may be as low as 5 inches.§

The 'sourness' of pasture-lands, when stagnant water lies about and the herbage is rank and coarse, has been attributed to an excess of organic acids, and to the absence of lime and available phosphate. Ants are said also to produce sourness of pasture, and it has sometimes been regarded as due to the silting up of land-drains. Such sour lands are generally improved by drainage and the application of lime.

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* *Morning Post*, November 30, 1911.

† 'Geology and Water Resources of the San Luis Valley, Colorado,' by C. E. Siebenthal. Water-Supply Paper 240, *U.S. Geol. Survey*, 1910, p. 27.

‡ See remarks in reviews by Dr. E. J. Russell, *Nature*, November 24, 1910, and October 26, 1911.

§ Professor C. Abbe, *ibid.*, October 7, 1909, p. 435.

In certain arid regions, as in America, there are low-lying tracts, with no outlet, that were formerly basins of salt lakes, or may still be liable to contain a certain amount of water. These are known as 'salinas.'

The term 'lick' in the United States is applied to swampy or boggy tracts where there are springs with sodium chloride, and the soil is encrusted with salt which the cattle come to lick. Hence the name Big Bone Lick in Kentucky, applied to a lick of great antiquity (Pleistocene), where bones of mastodon and other fossil animals have been found.

The term 'alkali soils' is applied in the Western States of America, North Africa, parts of India, and Australia, to soils that contain not only salts of sodium and potassium, but also salts of magnesium, calcium, etc. They include—

Sodium sulphate (white alkali).
,, carbonate (black alkali).
,, chloride.
,, nitrate.
,, silicate.
Potassium chloride.
,, carbonate.
,, silicate.
Magnesium sulphate.
,, chloride.
Calcium carbonate.

Sodium sulphate appears to be most abundant, and after that sodium carbonate and chloride. The black alkali is so called because it blackens the soil and the stems and roots of plants by a solution of humus. Alkaline silicates occur in some parts of Uruguay.

In explanation of the alkali soils, F. H. King (1899, p. 94) says: 'It seems plain that the high percentages of soluble ingredients in the soil of arid regions result from the slow decomposition of soil-grains, brought about by the conjoint action of the scanty water which does fall, and the carbonic acid of the air. Water enough falls for the decomposition of rock and the formation of alkalies and zeolitic minerals, but not enough to remove them when formed, as is the case in humid regions.'

Though in part of local origin, a good deal of the saline matter is derived from upland regions, and transported by streams or irrigation canals to lower grounds, where it saturates the porous strata. The alkaline subsoil water may reappear in the lowest tracts, or be otherwise brought to the surface by capillary action, and the salts are then deposited locally as efflorescences or encrustations on evaporation of the water. The dry saline matter is sometimes wind-drifted.

Much injury has been caused by black alkali, especially through excessive irrigation. To some extent this is a matter that may be remedied by under draining, to lower the level of the subsoil water, or by flooding areas to wash the saline matters from the soil. In other cases it may be desirable to divert the irrigation water at higher levels, and conduct it to better lands.*

Attention was directed many years ago to diseases termed 'splenic apoplexy' and 'scouring' (diarrhœa) that affected cattle and sheep on certain pastures on the poorer Lias Clays near Ilchester in Somerset. According to Professor J. Buckman, the complaints were due in part to the state of the herbage on the ill-drained meadows that were subject to floods. But more recently it has been suggested that this 'tart,' or 'teart,' land may possibly be due to the physical state of the soil. The alluvial pastures are not affected, and no evidence has been obtained to prove that the plants of the pastures are injurious, or that any disease organisms are present.*

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* O. E. Meinzer, 'Ground-Water in Utah,' Water-Supply Paper 277, *U.S. Geol. Survey*, 1911, p. 277.

WATER-MEADOWS.

Water-meadows, or grass-lands that are rendered more fertile by processes of irrigation for pasture or hay, have been established in many river-valleys, as along the Kennet in Berkshire, the Avon and Wiley in Wiltshire, the Avon and Stour in Hampshire, in Dorset, and Gloucester, at Clipstone Park, bordering the River Maun in Nottinghamshire, and elsewhere. Water in a channel, or *main feeder*, is diverted from the higher part of a main stream or tributary, sometimes from a copious spring, and conducted from the upper side of a meadow over gently sloping ground, by a series of minor open channels, or *floating feeders*, at successively lower levels, with *catch-drains* to carry away the water to the *main drain*, and thence to the lower course of the stream or river.

In other cases, however, the land may be flooded for a time to a depth of several inches.

The land surface is smoothed so as to present a fairly uniform gentle slope towards the valley bottom, and it must be properly drained, so that the water-meadows are dry after irrigation. When the subsoil is gravel, the land is well suited for water-meadows; in clayey and peaty ground, ridges and furrows are constructed.

It was the opinion of William Smith (1806) that 'all low meadows, or large districts of land which lie contiguous to rivers, and are subject to be flooded by fresh water, may reap the advantage of a double improvement by draining and irrigating.' He referred to the high antiquity of water-meadows, which he thus defined: 'A water-meadow is a piece of ground so formed by Nature or art that water may flow quickly over its surface for the purpose of promoting an early and increased vegetation of grass. There are but few natural water-meadows, and Wiltshire has to boast of some which probably gave the first idea of making them artificially.'

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* Buckman, *Bath and W. Eng. Agric. Journ.*, 1868, xvi.; C. T. Gimingham, *Nature*, November 3, 1910, p. 25; E. J. Russell, *ibid.*, May 11, 1911, p. 364, and September 28, 1911, p. 425.

One of Smith's noted achievements was the draining and improvement of Prisley Bog by Prisley or Priestley's Farm, near Tingrith, east of Woburn, in an alluvial valley bordered on the north by Lower Greensand, and on the south by Gault, with Drift.

Futile attempts, extending over eight years, had been made to drain the bog, but Smith determined to adopt the system of water-meadow irrigation, obtaining water from the brook and the upper part of the bog-land. In this undertaking he proved successful, and the ground was converted into good pasture and meadow land for hay.

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CHAPTER XII

MANURES, WITH ESPECIAL REFERENCE TO NATURAL MINERAL MANURES

WHILE affording indications of the capabilities of cultivation according to the nature of soil and subsoil, geology does not, of course, profess to deal with the crops, nor with the requisite manures. Yet, since it is one object of the scientific agriculturist to prescribe the kind of manure requisite and suitable for particular crops, soils, and conditions, geology has a distinct bearing on many practical questions that arise in regard to manures.

The manures are valuable in affording direct or indirect plant foods. Some influence the texture of the soil; others produce chemical changes, and render plant food available. Some produce acidity; others have the contrary effect.

Knowledge is therefore required of the mechanical, chemical, and mineralogical characters of the soils. Thus, for example, the presence or absence of carbonate of lime in soil is important with regard to the kind of manure that may be applied. Fertilizers are manures that supply one or two particular kinds of plant food as distinct from manures, such as that of the farmyard, which contains phosphates, potash, and nitrogen, etc.

Not only have the requirements of the crops to be considered, when there is a succession in the same field of different cereals, roots, and grasses, but also the rainfall and other climatic and seasonal conditions, so that the manure may be applied at an appropriate period. A good deal of soluble matter in the soil or imparted to it by manure, such as salts of soda, lime, and magnesia, will be lost during periods of rain.

Natural Manures include the following mineral and organic substances:

Clay, marl, shell-sand, chalk and ground limestone, gypsum.

Rock-salt (sodium chloride), 'Chile saltpetre' (sodium nitrate), and saltpetre (potassium nitrate).

Kainit (potassium and magnesium sulphate, and magnesium chloride, with also sodium chloride, and small amounts of potassium chloride and calcium sulphate); and Carnallite (potassium and magnesium chloride), are natural salts which occur in the Permian (Zechstein) strata of Stassfurt and other places in Germany. They are obtained from the salt-mines above thick masses of rock-salt, and below beds with gypsum.

Rock or mineral phosphates, apatite and phosphorite, phosphatic nodules and coprolites, guano.

Farmyard and stable manure, bones and bone-dust, fish refuse, seaweed, leaves and leaf-mould, peat-moss litter, cocoa-nut fibre, rape-dust, straw, etc.

Artificial Manures include the following:

Lime, calcium nitrate, calcium cyanamide (nitrolim).

Superphosphate, which includes sulphate of lime; basic slag, a waste product from phosphatic iron-ores (Thomas phosphate).

Ammonium sulphate, ammoniacal liquor.

Sodium sulphate, potassium nitrate, sulphate and chloride (muriate), magnesium sulphate, iron sulphate.

Bone-ash, soot, charcoal, wood and peat ash, shoddy or waste from cloth-mills, with oily matter, etc.

It is only with the chief natural manures, so far as they possess geological interest, that we are here immediately concerned.

Chalk, Marl, and Lime.—The advantages of an application of Chalk or of earth containing a good deal of carbonate of lime to land deficient in that substance have long been recognized. Indeed, the use of lime on the land probably dates from Roman times.

Lumps of Chalk or finely-ground limestone have been put in the land; sometimes quicklime or caustic lime, also slaked lime and gypsum.

Shafts were sunk in Buckinghamshire and Hertfordshire to obtain Chalk on the land that required it, such as tracts of Reading Beds, of Clay-with-flints, and associated mixed superficial deposits with relics of Eocene strata. Elsewhere, as on the London Clay of Middlesex, lumps of Chalk were strewn over the surface of the land, where ultimately they became buried in pasture-lands and rounded by weathering, so that occasionally layers of such nodules have been disclosed in railway-cuttings, as near Ealing. (See p. 83.)

In West Norfolk the great estate of Holkham was converted by Thomas Coke, afterwards Earl of Leicester, from a comparatively barren tract into highly productive land by the application of marl (commenced about the year 1725). The land is naturally formed of Chalk, with thin and irregular cappings of Boulder Clay, sand and gravel, and a light sandy soil. On such ground marl is reckoned to be better than Chalk, as it is more readily pulverized. In the Eastern Counties marl was obtained from the Boulder Clay of the district, a variable accumulation, usually stony and clayey, with lumps of Chalk, but much of it consisting of ground-up Chalk. (See p. 229.)

The process of marling or claying (sometimes termed 'gaulting') has been adopted in the peaty areas of the Fenland, where the soil is light and liable to be blown away, and it has proved beneficial in supplying a good texture for cultivation, and in retaining moisture. In some cases described by T. Hawksley it was found that, in the course of two or three years, the marl had 'gone down the depth of a foot or more, and it went on sinking in the course of years to 6 or 7 feet deep, and then the process was to begin the work over again.'*

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* *Proc. Inst. Civ. Eng.*, 1862, xxi., p. 104.

Heavy lands are improved and lightened by the application of lime, the physical character of the clay is modified, the acids of sour soils are destroyed, and the process of decay of animal and vegetable matter is facilitated.*

Marling and claying, carried out more or less extensively during medieval times, and to the early part of the nineteenth century, has since been generally abandoned, on account of the cost of labour. The numerous pits (now ponds), sometimes more than one in a field, scattered over the clay districts in England, testify to the amounts of earth put on the land. According to Arthur Young, from thirty to sixty loads per acre were applied, the load being about 36 cubic feet. The larger quantity was stated to last fifteen or sixteen years, when renewed dressings were given. He mentioned one instance, on a light soil at Waterden, west of Walsingham, in Norfolk, where 122 loads per acre were applied to a field, which, in consequence, was 'over-dosed,' and the crops failed.†

Marl and clay have been dug, for agricultural purposes, on the Permian and Triassic marls, especially the Keuper Marl; the Lias clays or marls; the Wadhurst clay and shale; Weald and Gault clays; and Boulder Clay. In general, the blue clays, which contain sulphide of iron, were not good for the land, and probably the brown, weathered clay subsoil, which may extend 6 feet or more in depth, was utilized. This, however, would not apply to the chalky Boulder Clay.

Shelly and Other Sands, Gravels, and Clays.—Shell-sand readily obtained in Eastern Suffolk and some parts of Norfolk from the Crag Series was first used as a manure in 1718. Wind-drifted beach-sand, largely composed of comminuted shells, has been put on the land in Cornwall, the Scilly Isles, and elsewhere. It has likewise been naturally drifted over wide tracts.

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* See 'The Liming of Land,' Leaflet No. 35, Dep. Agric. and Techn. Instr., Ireland.

† 'Agriculture of Norfolk,' 1804, p. 410.

Coralline sand, a marine product of vegetable origin found on the Galway coast, and rich in calcareous matter, has been used as a manure (J. R. Kilroe, 1907); also shell marl from alluvial areas in the Kennet Valley, etc., as well as from Inchrye, near Newburgh, in Fifeshire.

The 'manure gravels' of Wexford have been found serviceable for land dressings, on account of their shelly character.

Sand devoid of calcareous matter has not been found of value as a dressing on clayey soils, but it has been used with advantage on some upland peaty moorlands. Topley stated that the siliceous rock of the Upper Greensand (malmstone), which contains 20 to 70 per cent. of soluble silica, and is often calcareous, had been dug at Farnham, and extensively used as manure.

In Norfolk the fossiliferous Nar Valley brickearth, of Pleistocene age, was used as a manure. In reference to it, Arthur Young remarked that, 'In East Winch and West Bilney, and scattered for ten miles to Wallington, there is a remarkable bed of oyster-shells in sea-mud: the farmers use them at the rate of ten loads an acre for turnips, which are a very good dressing; they are of particular efficacy on land worn out by corn.' The shells are tender, as they 'fall to powder on being stirred.'*

It has been observed by the Rev. Hilderic Friend that 'the ooze of rivers is immensely enriched in nitrogenous matter year by year through the death of annelids, as well as oxygenated by their tireless movements.' Nile and Thames muds are thus fertilized.†

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* 'Agriculture of Norfolk,' 1804, p. 413.

† *Nature*, September 21, 1911, p. 381.

Estuarine mud from the bottom of Yarmouth Haven was used as manure on land at Coltishall, and on the sandy loams of Warham, with great advantage.

Salt, Charcoal, and Seaweed.—Common salt has been used on the land to render soils moist, and to keep them soft in frosty weather. Moreover, it is useful in destroying some weeds and insects. In Cheshire the refuse-salt with earthy matter is used as manure.

Charcoal has been put on the land to increase the absorbent power of the soil.

Seaweeds, the larger kinds known under the general name of 'kelp,' are put on the land in various parts of the British Islands, as they supply potash, nitrogen, etc. The term 'kelp' is also given to the ashes of seaweed.

CLAY-BURNING.

On some poor barren or waste lands, paring and burning of the surface soil, stubble and sward, for a depth of about 2 or 3 inches, have been adopted. The sods, when stripped from the surface, were slowly burned in heaps, and the ashes were afterwards put on the land.

This process has been adopted when fresh ground was enclosed in the Fenland, on some clayey tracts, and on others where pasture was to be converted into arable land. Clays which contain silicate of potash, and some carbonate of lime, are improved by burning; but the process is almost obsolete, since liming and underdraining are regarded as more efficacious.

On loose sandy soils the paring and burning were not advantageous. Otherwise, the burnt material on heavy land lightened the soil, formed a manure, and the process killed weeds and insects. The practice of 'clod-burning' was general on the strong, loamy, and clayey lands of Suffolk about a century ago; then vegetation from ditches and the borders of fields were burnt with the clods of soil, and the material, to the extent of fifteen to thirty loads per acre, was spread on the land after fallow and ploughed in.*

Mineral or Rock Phosphates.

Apatite, which consists of about 89 per cent. of calcium phosphate, contains also calcium fluoride and chloride. It occurs in igneous and metamorphic rocks, and in veins and pockets associated with them, notably in Norway, Canada, and the United States, and from these sources, and especially from the basic igneous rocks, the phosphatic matter in the ordinary sedimentary rocks, of all ages, has been obtained. Nevertheless, as remarked by Dr. J. J. H. Teall, 'If we leave out of account the very small amount of detrital apatite, it is highly probable that the whole of the phosphorus found in the sedimentary rocks has been derived, either directly or indirectly, from the waters of rivers, lakes, and seas, by the action of organic life.' He points out that organic agencies 'may produce phosphatic deposits either—(*a*) directly, by the accumulation of organic remains, as in the case of guano and bone beds; or (*b*) indirectly, by furnishing phosphatic solutions which may percolate downwards, and act as metamorphosing agents on the underlying rocks.'† Thus sandstone, limestone, and even trachyte, have become phosphatized, the last-named into a phosphate of alumina.

Phosphorite, a concretionary semicrystalline and more soluble form of apatite, constitutes the principal economic deposits of phosphate. It has been obtained at Estremadura, in Spain (no longer worked), South-West France,

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* H. Raynbird, *Journ. Roy. Agric. Soc.*, viii., p. 261.

† 'The Natural History of Phosphatic Deposits,' *Proc. Geol. Assoc.*, 1900, xvi., pp. 372, 373. See also H. Hicks and W. H. Hudleston, *Quart. Journ. Geol. Soc.*, 1875, xxxi., p. 368.

Germany, North Africa, Florida, and the Eastern Carolinas. The chief supply now comes from the United States.

Phosphatic nodules have been formed by concretionary action from water charged with phosphatic matter, derived from animal remains, such as brachiopods, trilobites, fishes, etc.

Fossils and casts of fossils have been phosphatized, or coated with phosphatic matter. Among these are fragments of wood, foraminifera, sponges, and various higher organisms up to vertebrate remains.

True coprolites, or fossil fæces, occur somewhat rarely in the Rhætic Beds, Lower Lias, and other formations; but the term has been applied commercially to phosphatic nodule-beds containing nodules and phosphatized fossils, and only occasional true coprolites. Rock, or mineral phosphate, has in some instances been ground and put on the land.

Guano, in most cases mainly formed of the excrement of sea-birds, with other organic débris, has been obtained in regions where little rain falls, notably on islands off the coasts of Peru and Chile, and to a small extent on the mainland. There the material is known generally as Peruvian Guano, of which large quantities have been exported, but the supply is not yet exhausted.* Guano has also been obtained from Cape Colony and Ichaboe Islands, South Africa, Patagonia, the Falkland Islands, and Australia. The compounds are mostly soluble, and can only be preserved in regions of little rainfall. Those from the above-mentioned localities are for the most part phosphatic and nitrogenous, some having 9 per cent. or more of nitrogen, and about 40 per cent. of phosphate.

Other deposits which have been washed by rains are non-nitrogenous, and occur in the West Indies (Tortola,

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* See 'Map of Peru, with Explanatory Notes,' published by Peruvian Minister of Foreign Affairs, 1903.

Aves, Mona), in some of the Pacific Islands (Christmas Island, phosphatized limestone), Bolivia, Arabia (Kooria Mooria), etc.

Nitrogenous guano from bats' deposits has been obtained from caves in Texas and Mexico, and nitrogenous and also silicified guano have been obtained from caves in Western Australia.

Geological Horizon of Some Rock Phosphates.

Archæan.—Canada (apatite), Norway (apatite).

Cambrian.—Pembrokeshire, Nuneaton, New Brunswick, Sweden, South Australia.

Ordovician.—Llanfyllin and Llangynog, near the Berwyn Mountains, on the borders of Montgomery and Merioneth, phosphorite mined at top of Bala limestone; Sweden, Tennessee.

Devonian.—Nassau (phosphorite), Tennessee (veins and pockets).

Carboniferous.—Yoredale Series, Swarth Fell, Westmorland (nodules).

Rhætic.—England. Nodules in bone-bed of Black Shales.

Lias.—Nodules and phosphatized fossils in Lower Lias, Radstock; also Lorraine; nodules in Middle Lias, Lincolnshire.

Inferior Oolite Series.—Dogger Series, Yorkshire; base of Inferior Oolite, Ben Tianavaig, south of Portree, Skye.

Cornbrash.—England (calcic phosphate, traces).

Kimeridge Clay.—England (nodules).

Lower Greensand.—Wicken and Upware, Cambridgeshire; Little Brickhill, Buckinghamshire; Sandy and Potton, Bedfordshire; Speeton Clay, Yorkshire (nodules).

Gault.—West Dereham, Norfolk; Upware, Cambridgeshire; Towersey, Buckinghamshire; Folkestone, etc. (nodules). France: Provence, Boulonnais. Belgium: Hainaut.

Upper Greensand.—Upper part locally phosphatized, Farnham, Surrey. France: Marne (nodules).

Chalk.—'Cambridge Greensand,' nodules and phosphatized fossils at base of Chalk, Cambridge, etc.; Ashwell, Hertfordshire; Shillington, Bedfordshire; Farnham, Surrey (nodules, etc.). Phosphatized Chalk, phosphatized foraminifera, shell and fish remains in calcareous matrix, Taplow, Buckinghamshire; also Lewes, Sussex. France: Somme, Pas de Calais, Picardy, etc. Belgium: Mons and Ciply in Hainaut (phosphatized Chalk).

Eocene.—Algeria and Tunis (phosphatized limestones).

Oligocene.—France: Quercy (phosphorite).

Pliocene.—Coralline Crag, phosphatized sandstone (box-stones), etc. Red Crag, nodule bed at base with coprolites, London Clay fossils encrusted with calcic phosphate; there also occur pebbles of flint and sandstone. South Carolina and Florida (nodules and boulders, bones, and phosphatized limestones).

Recent.—Sombrero, West Indies (phosphatized limestone, nearly exhausted).

Nitrates.

Sodium nitrate in rainless districts of Chili, Peru, and Bolivia; also on borders of California and Nevada in surface deposits.

Potassium nitrate in Spain, Portugal, India, Chili, Peru, in surface deposits.

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SOMERVILLE, W. (See p. 108.)

CHAPTER XIII

FORESTS AND WOODLANDS, AND THE GEOLOGICAL FEATURES IN CONNECTION WITH THEM

SINCE the time when man first appeared on the scenes in European areas considerable physical changes have taken place. Large areas in Northern Europe and Britain have been covered with superficial accumulations and greatly eroded, while the fauna more than the flora in Britain has been considerably modified. That parts of our country were occupied by man during Pleistocene times is undisputed, but whether prior to the Glacial Epoch is a matter not clearly established.

It was not until after the commencement of the Holocene or Recent Period that the land had so far settled that the relative levels of land and sea became stationary; and if we turn to the earlier or Neolithic portion of that period, which dates back about 7,000 years, we may conclude that the greater part of the country was woodland, with open tracts of heath and moor, and grassy down on some of the more hilly tracts. These would comprise certain Chalk Downs, where the ground is but little covered with Clay-with-flints. Elsewhere extensive marshes and swamps occurred over the alluvial areas. Some of the more ancient human settlements were on the open Chalk tracts. (See p. 170.)

Mr. Clement Reid has drawn attention to 'a curious relic of the ancient settlers' on the Chalk Downs of the South of England. In Hampshire, 'at the foot of the Chalk hills, generally near to the junction of the dry Upper and Middle Chalk, which form the open Downs, with the marly Lower Chalk, which was covered with forest, is often found a thick, bushy hedge, which can be traced for long distances, and also occurs under similar circumstances in other counties. This hedge will at once strike the attention as something exceptional; for, unless replanted in modern times, it contains little hawthorn, and is very wide. It consists of a belt of small trees, among which maple, cornel, sloe, hazel, buckthorn, wayfaring-tree, elder, holly, and spindle-tree predominate, and are mixed with beech, ash, stunted oak, yew, crab-apple, and service-tree. In short, it appears to be a relic of the vegetation of the original margin of the native forest, rendered denser and trimmed to a certain extent, but in other respects not greatly altered. . . . At the present day the hedge separates the open Chalk pastures from the arable land, and, as that has always been a convenient boundary, it has commonly been left undisturbed, or has been replaced by a narrower hedge of hawthorn.'*

In many areas the names alone survive of the ancient woodlands, and, further, it is impossible to define the limits of the areas to which forest names had been applied.

The character, also, of the woodlands has been altered by the introduction from one part of Britain to another of trees like the Scotch fir and beech, and the introduction of other trees from abroad; therefore modern plantations, as a rule, are more varied than the ancient woodlands.

In Neolithic times, as pointed out by Mr. C. Reid, pine forests, with Scotch fir, occurred over extensive districts in the South of England, becoming afterwards locally extinct, and only reintroduced abundantly during the last hundred years.*

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* 'Victoria History Hampshire' (article 'Geology'), vol. i., 1900, pp. 16, 17.

Among the wild animals, the remains of which are preserved in Recent (Holocene) deposits, are the Irish elk (extinct); the moose or elk (extinct in Britain); the reindeer, which existed in Caithness until 1159; the brown bear, which lived in Britain until Saxon or Danish times, but not after the ninth century; the wolf, which was exterminated in England during the reign of Henry VII. (1485-1509), and in Wales during the early part of the seventeenth century, but is considered to have lived in Scotland until the first half of the eighteenth century; the beaver, which became exterminated in Wales about the end of the twelfth century; and the wild boar, exterminated in Wales during the fifteenth (or possibly sixteenth) century, appears to have lived in England to nearly the close of the seventeenth century, and later in Scotland and Ireland.†

Woodlands, and vegetation generally, tend to check and regulate the flow of rain to streams, and thereby to diminish floods; otherwise they appear to have no effect on the amount of rainfall. Where the land has been cleared of trees, streams which flowed during all seasons are more copious after rain, and may cease to flow in dry seasons. In the exposed areas, heavy rain will trench the hillsides, and carry down soil and subsoil from the surface of the higher grounds, in some cases choking streams and silting up rivers.

In certain parts of India the protection afforded by forest reserves 'has completely changed the character of the torrents and streams, taking their rise in the forests. After rain, the water no longer rushes down, carrying sand and silt with it; the channels have been confined into permanent beds; they have become narrower and deeper, and the old beds to the edge of the channel have become stocked with grass and thousands of seedlings.'‡

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* *Proc. Dorset Nat. Hist. Club*, 1895, xvi., p. 14.

† J. E. Harting, 'British Animals Extinct,' 1880; H. E. Forrest, 'Vertebrate Fauna of North Wales,' 1907.

‡ B. Ribbentrop, 'Forestry in British India,' 1900; *Nature*, April 18, 1901, p. 597. See also H. B. Maufe (Muff), 'Colonial Reports—Miscellaneous,' No. 45, East Africa Protectorate, 1908, p. 60.

In Ross-shire and Inverness-shire woods with pine and birch extend over mountainous ground up to about 1,200 feet, and some trees are found at greater elevations (see p. 145); but the average height of land under timber is from 400 to 500 feet, and afforestation is not regarded as likely to be profitable at higher elevations than 900 to 1,000 feet. Indeed, exposed situations above 700 or 800 feet in mountain regions are regarded by Mr. A. C. Forbes as unsuitable to the growth of large timber.

In Denbighshire, according to Mr. W. E. Frith, successful plantations have been made up to 1,300 feet; and in Cumberland, between Cross Fell and Nenthead, south-east of Alston, as noted by Mr. Forbes, there is woodland, mainly spruce, with also Scotch fir, ash, and beech, that extends to from 1,250 to 2,000 feet in elevation, the soil consisting of 1 or 2 feet of peat over Glacial Clay and Yoredale Limestone.

While the majority of forest trees naturally prefer a rich loam more or less gravelly and peaty, 2 or 3 feet deep, with good subsoil, yet it will be found that woods exist on diverse soils and substrata. The oak may be seen growing on pebble gravel and on Chalk in Surrey, on clay slate in Cornwall, on grits in West Somerset. The Scotch fir grows on Chalk. Nevertheless, many of the trees do not fully develop, unless the soil and subsoil and physical conditions are altogether favourable.

The distinction is well marked in some localities, as in the neighbourhood of Croydon, where the bridle-way to Addington roughly separates a fir-clad gravel hill on the north, from a grove of beech-trees on the Chalk to the south.

Most trees are injured by stagnant surface or subsoil water, and drainage is necessary. In plantations for timber it is therefore needful to consider the adaptation of particular trees to the land, and of mixtures of trees, some affording protection to others by foliage and leaf-canopy, as noted by Nisbet (1894).

Tree-roots may extend downwards to a depth of 7 or 8 feet or more according to the subsoil. If rocky ground, the roots find access through joints and fissures, but it has been observed that in Chalk trees have a difficulty in extending their roots deeply, although the beech thrives on that formation when the soil is but a few inches thick. Many roots extend 20 feet or more from the trunk near the surface; in some instances nearly 100 feet.

According to Nisbet (1894), the oak and larch require a deep soil; the elm, ash, maple, sycamore, silver and Scotch firs, a moderately deep soil; the beech, hornbeam, and alder, soil of less depth; and the spruce, aspen, and birch, the least depth. Here shallow soils are reckoned at less than 1 foot, medium soils at 1 to 2 feet, and deep soils at 2 to 4 feet. The deeper soils would often include clayey and loamy subsoils.

Plantations may be made on ground that has a slope of about 30 degrees, and is too steep for arable cultivation, as may be seen on the scarps of the Cotteswold Hills, the North and South Downs, on the lower slopes of mountains and moorlands, and sometimes in railway-cuttings. On some steep rocky slopes the loose talus is apt to slip, and the soil may be washed away.

In Sussex, as observed by Mr. C. Reid, certain steep Chalk slopes 'seem always to have been clothed with ancient hanging woods, locally known as "hangers," principally of beech, with some undergrowth of holly and hazel.'*

Of recent years public attention has been directed to afforestation,† and in this connection may be added a few notes which bear on the geological side of the question.

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* 'Geology of Chichester,' *Mem. Geol. Survey*, 1903, p. 22.

† See 'Royal Commission on Coast Erosion and Afforestation,' 1909, and 'Report of Committee on British Forestry,' 1902.

Dr. W. Somerville is of opinion that beech might be grown on some of the poorer and exposed downlands in the Chalk districts of Wiltshire and Dorset. On Salisbury Plain, Scotch fir, larch, and silver fir, grow in places, but as a rule there is no evidence of old forests on the higher Chalk Downs, unless where covered by tracts of Clay-with-flints. Nevertheless, wooded areas are found from Arundel Park by Houghton, Charlton, and Singleton Forests, to Goodwood Park in Sussex, where only occasional patches of Clay-with-flints are shown on the Geological Survey Map.

The Lincolnshire Wolds, in Mr. Reid's opinion, might advantageously be planted.*

Some of the poorest land in England is that on the Canford estate, near Wimborne in Dorset, on Bagshot sands and gravels. There the soil is hard, ferruginous, and gravelly, with some peaty loam, and it gives rise to poor heathy ground. Dr. Somerville, however, is disposed to regard it as capable of afforestation, as plantations of Scotch fir have been established in places.† Perhaps also some of the derelict lands of Essex might similarly be considered. (See p. 111.)

Among other areas suggested for afforestation are the uplands north of Dartmoor, on the grits and shales of the Culm Measures, also the moorlands of Westmorland.

It was remarked many years ago by H. Tanner that Woodbury Common in East Devon might be advantageously planted, as firs thrive well on the land.‡ It is formed of pebble-beds and sands of the Bunter formation, with peaty soil in places.

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* 'Geology of Holderness,' *Mem. Geol. Survey*, 1885, p. 120.

† 'Report of Royal Commission on Coast Erosion,' etc., 1909, vol. ii., part ii., pp. 291, 396.

‡ *Journ. Roy. Agric. Soc.*, 1848, ix., p. 486.

Mr. L. W. Hinxman has suggested that large areas under 1,000 feet of now barren moorland among the Highland Schists and Valley Drifts of Strath Conon, Glen Orrin, and Glen Strathfarrar, on the borders of Inverness, Ross, and Cromarty, might be planted.*

BRITISH TREES.

The following is a list of the more abundant trees in Britain, including some of ornamental character that have been introduced (marked*), with notes on the soils best adapted for them :

*ACACIA (*Robinia pseud-acacia*).—Sandy loam.

ALDER (*Alnus glutinosa*).—Alluvial swampy grounds. Alder cars.

APPLE (*Pyrus malus*).—Wild or crab apple. Loam and marl.

ASH (*Fraxinus excelsior*).—Deep sandy loam, marl, limestone, up to about 1,000 feet.

BEECH (*Fagus sylvatica*).—Chalk, sandy and gravelly loam.

BIRCH (*Betula alba*).—Common white or silver. On most soils, sandy, gravelly, and rocky, up to 2,000 feet.

BOX (*Buxus sempervirens*).—Limestone.

*CEDAR OF LEBANON (*Cedrus libani*).—Mixed soils.

CHERRY.—*Prunus cerasus :* Dwarf cherry, from which garden cherry is considered to be derived. *Prunus avium :* Wild or gean cherry. *Prunus padus :* Bird cherry. Mixed soils, sandy and gravelly loam.

CHESTNUT.—**Æsculus hippocastanum :* Horse-chestnut. Deep loam. **Castanea sativa :* Spanish or sweet chestnut. Deep sandy loam.

CYPRESS (*Cupressus sempervirens*).—Deep sandy soil.

ELDER (*Sambucus nigra*).—Various soils.

ELM.—*Ulmus campestris :* Deep loam and marl ; largely hedgerow timber. *Ulmus montana :* Wych or mountain elm. Various soils.

HAWTHORN (*Cratægus oxyacantha*).—Whitethorn or may. Various soils ; hedgerows.

HAZEL (*Corylus avellana*).—Calcareous and loamy soil.

HOLLY (*Ilex aquifolium*).—Limestone, sandy and gravelly loam, rocky soil.

HORNBEAM (*Carpinus betulus*).—Clay and strong loam.

JUNIPER (*Juniperus communis*).—Limestone.

*LABURNUM (*Laburnum vulgare*).—Loam, and most soils fairly moist.

*LARCH (*Larix Europæa*).—Sandy loam, Chalk, etc., up to 1,200 feet.

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* 'Summary of Progress,' *Geol. Survey for* 1901, p. 104.

*Lime (*Tilia Europæa*).—Linden. Loam, fairly moist.

Maple (*Acer campestre*).—Loam, marl, limestone.

Mountain Ash (*Pyrus aucuparia*).—Rowan. Most soils, rocky, fairly dry, up to 2,600 feet.

*Mulberry (*Morus nigra*).—Well-drained sandy loam, sheltered.

Oak.—*Quercus robur*: Clay, loam, and marl, up to 1,200 feet. **Quercus ilex*: Evergreen oak, holm, or ilex. Sandy loam.

Pear (*Pyrus communis*).—Loam.

Pine (*Pinus sylvestris*).—Scotch fir or Scots pine. Sandy, gravelly, and rocky soil.

*Plane (*Platanus orientalis*).—Mixed soils.

Plum.—*Prunus communis*: Common plum. *Prunus domestica*: Wild plum. *Prunus spinosa*: Blackthorn or sloe. *Prunus interstitia*: Bullace or damson. Clay and marl.

Poplar.—*Populus nigra*: Black or common poplar. **Populus fastigiata*: Lombardy poplar; wood for churns. *Populus alba*: White poplar. *Populus tremula*: Aspen. Alluvial ground and hedgerows.

*Spruce (*Picea excelsa*).—Norway spruce. Sandy, gravelly, and rocky soil, fairly moist.

*Sycamore (*Acer pseudoplatanus*).—Loam, marl, Chalk.

*Walnut (*Juglans regia*).—Deep sandy loam, limestone.

Willow.—*Salix alba*: White willow, as osiers (pollarded); paper pulp; salicin. *Salix fragilis*: Crack willow, as osiers (pollarded); withy beds. *Salix viminalis*: Common osier. *Salix triandra*: Long-leaved willow, as osiers (pollarded); on marshy tracts (cars). *Salix cinerea*: Sallow. The above on moist alluvial soils, but not on deep bog. *Salix caprea*: Goat willow. Fairly dry soils.

Yew (*Taxus baccata*).—Limestone, and sandy, gravelly, and rocky soils.

Oak and beech have been much used for charcoal-burning, as fuel for household use, and also, in the case of the oak in particular, for smelting in the iron furnaces of the Weald, etc. The burning was recently revived for a time at 'Cuckoo Pits,' near Chingford, as described by Mr. S. H. Warren.* He points out that the product was generally called 'coal'; hence the names 'Cole Field' are met with here and there in areas far away from true coal districts. Alder, birch, evergreen oak, hazel, hornbeam, horse-chestnut, lime, maple, pear, spindle-tree, sycamore, and willow, have also been used for making charcoal, for gunpowder, and various other purposes.

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* *Essex Naturalist*, 1910, xvi., p. 65.

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CHAPTER XIV

ORCHARDS, MARKET GARDENS, AND VINEYARDS

Orchards require to be well-drained, with shelter from strong winds, and they thrive best in fairly mild districts. Experiments at the Woburn Fruit Farm show that grass in orchards is injurious to the full growth of the trees.

Apple-trees flourish on gentle slopes with loamy soils of good depth: on the Old Red Sandstone, the Permian and Triassic sandstones and marls, and on the Lias, especially on the calcareous sandy loams of the Middle Lias. In some instances, in the Lower Lias of Somerset, old quarries have been converted into orchards, when the stone has been worked out; the ground is then levelled, drained, and covered with soil. The more favoured districts lie in Devon, Somerset, Dorset, Gloucester, Hereford, and Worcester. Nevertheless, there are varieties of apples suited to different districts. There are orchards in the lowlands of Edinburgh, and many are being planted throughout Ireland.*

Pear-trees, as a rule, require a deeper and richer soil than the apple; but they flourish on the formations before mentioned, growing sometimes on the Chalk, and on decomposed igneous rocks in Jersey and Guernsey.

Among 'small fruits,' cherry orchards thrive on deep and rich loamy soils, such as may be found on the Lower

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* See Leaflets Nos. 55 and 64, Dep. Agric. and Techn. Instr. for Ireland.

Eocene strata and valley brickearths in East Kent, and also on loamy soils above the Chalk, as in tracts south of Canterbury.

Strawberries are grown on light, loamy, and gravelly soils of the Valley Drifts and Lower Eocene of North-West Kent, and on the loamy and chalky soils of Sussex, near Worthing, etc.

Plum-trees thrive on the clays and gravelly loams of the Lower Lias and valley deposits bordering the Avon, near Evesham, and Pershore in Worcestershire, and adjacent parts of Gloucestershire.

Small fruit is cultivated on the valley gravels and brickearths over the Oxford Clay at Somersham and Bluntisham in Huntingdonshire, on the Gault with Drift coverings at Histon, north-west of Cambridge, on the Old Red Sandstone in Breconshire, and in many other localities.

Market Gardens for vegetables and fruit, and nursery grounds for trees, shrubs, and flowers, are usually situated on fairly light, loamy, or sandy and gravelly soils, preferably 2 or 3 feet deep. Favourable situations are met with along many river-valleys, notably along the Thames and its tributaries the Cray and Lea, the Ivel at Biggleswade, and the Trent in Nottinghamshire; also in the lowlands of Edinburgh, and in those bordering the sea from Southampton and Fareham, in Hampshire, eastwards to Worthing and Shoreham, near Brighton.

The Lower Greensand, also, near Biggleswade, Sandy, and Potton, and the Upper Greensand, near Market Lavington in Wiltshire, the greenstone and killas soil of Penzance (manured with seaweed and shell-sand), are noted regions for the culture of vegetables.

Herbs, including sweet herbs for scent and flavouring, and others employed as drugs for medicinal purposes, were grown in old monastic and physic gardens. Many are indigenous species, others were introduced; and they are of various classes, requiring some of them dry and others moist situations.

Sandy and gravelly loam has been the general soil in the famous Mitcham district for lavender, etc.; but the plants are now grown largely on a chalky subsoil farther south. Saffron, derived from the orange-coloured stigmas of *Crocus sativus*, has been cultivated on large tracts of loamy clay over Chalk, between Saffron Walden and Cambridge.*

Hops.—Hops are best cultivated on a deep, rich, and preferably calcareous loam, in fairly sheltered and sunny situations on southerly slopes. In Kent they are grown on the Thanet and Woolwich Beds, on the loamy and clayey soils of the Sandgate Beds, Hythe Beds, and Atherfield Clay; but mostly on loam, with occasional fine gravel, which overlies the Weald Clay, the chief districts being in the neighbourhood of Hadlow, Tonbridge, and Maidstone. They are cultivated also in Sussex, Hampshire, and Berkshire.

In Surrey hops have been grown on the Upper Greensand and Gault of Farnham; and Topley considered that the Upper Greensand of the Vale of Pewsey would be suitable land for their cultivation.

In Worcestershire (Teme Valley), Herefordshire, and Monmouthshire, hops are grown on the New Red and Old Red Sandstone and valley deposits. To smaller extents, hops have been cultivated in Gloucester, Wiltshire, Shropshire, Nottingham (Ollerton), Lincoln, Suffolk, and Essex.

Vineyards.—The soil on which the vine thrives, though regarded of much importance, varies greatly in character;

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* J. Clarke, *Essex Naturalist*, 1887, p. 9.

it is not necessarily very rich, but it should be well drained, and able to retain warmth and a certain amount of moisture.

Phosphatic fertilizers appear to be desirable where the soil is deficient in phosphoric acid.* The vine flourishes on certain deep loose rocky or stony soils, and, where the texture of the soil makes it fairly permeable, on argillaceous, sandy, and calcareous soils, with permeable, sandy, loamy, or rubbly subsoils of good depth. The situation and aspect of the vineyard, with southerly slopes in Europe, are regarded as of great importance, the stronger wines, port and sherry, being produced in the warmer regions. Stock from the same varieties of plants will yield different qualities of fruit in different regions and situations, and on different soils in the same district.

In the Bordeaux district (Gironde) the soils are of somewhat mixed character; there are vineyards on gravel, sandy gravel, sand, clayey soil, limestone, and on 'alios,' a term applied to quartzose grit or gravel cemented by organic and ferruginous matter—a kind of pan, more or less disintegrated. (See p. 197.)

In the Champagne district (Ardennes, Marne, Haute Marne, and Aube) the vineyards are situated on calcareous, clayey, and sandy soils, the last improved sometimes by claying, the substrata being Chalk, Lower Cretaceous, Jurassic rocks, and Alluvium. It was observed by Prestwich that in this district 'vineyards long yielding red wines only now produce white, without change of vines.'†

In the Burgundy district (Yonne, Côte d'Or, and Saône-et-Loire) the vines grow on various calcareous, clayey, and sandy soils, based on Tertiary, Cretaceous, and Jurassic strata, and on mixed igneous rocks on the borders.

It was remarked by G. P. Scrope that, in the old province of Auvergne (Puy-de-Dôme): 'From its proximity to the populous town of Clermont, the surface of the Cheire of Graveneire has been forced into cultivation by the most assiduous industry. The process is to break up all the projecting masses of basalt by blasting; and from their fragments and scoriæ, aided by dressings, a soil has been created and clothed with vineyards, which almost rivals the well-known fertility of the sides of Etna and Vesuvius, where the same method has been constantly pursued.'*

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* *Nature*, January 25, 1912, p. 429.

† Report on Wines, etc., *Internat. Exhib.*, 1862, pp. 7, 13.

In Germany vines are cultivated along the steep valleys of the Rhine and Moselle, where the Devonian rocks yield loose, slaty, and quartzose clayey soils. The earth, as in other similar situations, is retained on terraces by walls, and the downwash is sometimes carried up again to replace the lost soil.

In Portugal, the Alto Douro district, famed for port, is a mountainous and rocky region of schists and granite, with vineyards on terraces, where the soil is banked up by stone walls.

In the south of Spain (Andalusia) the vineyards on the Sierra Nevada have a deep soil of decomposed clay-slate. Farther east, in the sherry district of Xeres, or Jerez de la Frontera, Cadiz, the best soil, known as 'Albariza,' is a white or yellowish-white calcareous soil, with some magnesia and an admixture of sand and clay.

Among other soils, those of a sandy nature are known as 'Arenas,' while the red, more or less ferruginous earthy soils, which locally include clay and calcareous sand and gravel, are known as 'Barros.' These three types of wine-soils are found also in Sicily.

The best Italian vines are said to be those grown on the volcanic soils of the slopes of Vesuvius. In Hungary the best wines of Tokay are made from grapes grown on argillaceous, non-calcareous soil, derived from the decomposition of trachyte; other soils, derived from rhyolitic tuff and loam, produce wines of inferior quality.*

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* 'Geology and Extinct Volcanoes of Central France,' 2nd edit., 1858, p. 86.

In the south-west part of Cape Colony, according to Professor P. D. Hahn, vines are grown along the coast districts on stiff clays, disintegrated slate, granite, etc., the soils being poor in lime and somewhat 'sour,' but they do not require irrigation in the summer season. In inland districts, where the soils consist of fairly calcareous and porous loam, irrigation is necessary.†

The interesting subject of 'Vine-Growing in England' has been dealt with by Mr. H. M. Tod (1911).

Orange-Growing.—The following notes on orange cultivation in Western Australia are contributed by Mr. Bernard H. Woodward, Director of the Museum at Perth, Western Australia. There is an old saying that 'the orange-tree must have its feet dry,' which means that the soil in which it is planted must be well drained. The trees want plenty of moisture, but standing water kills them. A rich porous soil is absolutely necessary, and a deep alluvium intermixed with decomposed granite or limestone, with a porous subsoil, offers the best conditions; but any good loam, or sandy loam, of sufficient depth, with good drainage, is excellent. Chemical manures are better than stable manures. Orange-trees bear heavy crops, and require to be kept supplied with phosphoric acid, potash, and nitrogen. On a tract of ten acres there will be put in one year, say—

(*a*) 3 tons superphosphates }
(*b*) 1 ton sulphate of potash } in August.
(*c*) ½ ton sulphate of ammonia }
(*d*) 5 tons ground limestone in March;

and subsequently—

(*e*) Sulphate of iron, ½ pound per tree.

(*a*) and (*b*) must be applied annually. (*c*) It is as well to plant peas, or *Melilotus*, or other leguminous plant (in the Australian winter) carrying on its roots nitrogen-fixing bacteria, and ploughing in the plants in early spring (September), instead of using ammonia. (*d*) is applied, say, once every five years. The soil is deficient in lime, also in soluble iron salts—hence the need of (*e*).

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* J. Szabó, *Quart. Journ. Geol. Soc.*, 1866, xxii., part ii., p. 16.

† *South Afric. Journ. Sci.*, 1911, vii., p. 122.

CHAPTER XV

GEOLOGICAL CONSIDERATIONS CONCERNING ESTATES, MINERAL RIGHTS, AND ECONOMIC MATERIALS GENERALLY

In all endeavours to estimate the value of an estate, a knowledge of the nature and extent of the substrata is imperative. It is important with regard to the soils and subsoils, the amount and level of ground-water, the nature of springs, the drainage, the water-supply, and underground mineral rights. Among the many duties that fall to the agent or factor of a large estate is that of keeping a record of the land, and to render this complete such details as those mentioned above should find a place.

The publication of the large-scale Ordnance maps, 6 inches and 25 inches to a mile, has necessarily limited the work of land surveyors; and, so far as the topography of an estate is concerned, additions of buildings, roads, fences, etc., or any alteration or removals can be readily indicated on the published sheets.

On the 25-inch maps complete records of field operations can be kept, as pointed out by Mr. F. J. Bennett* in an interesting article, which we here utilize, with some modifications. The information that might be gathered includes the following:

1. Names of each field. (See pp. 146, 147.)
2. Soils and subsoils. Notes of their character and depth in all excavations made for gates, fences, cess-pits, land-drains, etc.

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* *Land Agent's Record*, August 20, 1904.

3. Courses of drains.

4. Cultivation of fields, whether arable, pasture, meadow, and woodland, and the changes made from time to time. Year by year, on each of the field-divisions marked on the map, there should be noted the amount of seed sown, the kind and quantity of manure used, and the weather at the time; also the result of the crop, such as weight of grain, length of straw, etc., and the same with other crops. If the results of seven years were thus recorded, the reason for success in one year and failure in another might be determined, while the varying results where different manures had been used could be noted in a field-book. The different kinds of trees and their growth in relation to the soil should also be recorded.

5. Springs and mineral waters.

6. Intermittent streams in Chalk and other limestone districts.

7. Wells and well-borings, with notes of strata passed through (nature of rocks and thicknesses), total depth, ordinary depth to water, and fluctuations in water-level.

8. Pits and quarries, material excavated, and whether used for marling or claying land, for brick or tile making, building stone, lime, mortar, silver sand, road-metal, etc.

The information obtained in part from old estate records, and largely by personal observation, would be of the highest importance to any subsequent tenant or owner, and, as Mr. Bennett points out, it should be of pecuniary value.

Mineral Rights Duty, according to the Finance Act of 1910, is payable in respect of the rental value of all rights to work minerals and of all mineral wayleaves (that is, right of way rented by mine-owners, etc.). But, on the other hand, there have been exempted from the Mineral Rights Duty common clay, common brick-clay, common brickearth, sand, chalk, limestone, and gravel, and (subsequently) road-stone.

The question, 'What is a mineral?' has engaged the attention of Law Courts on several occasions in reference to clay in general, and to china clay and oil shale in particular, and also in connection with 'mineral rights' at and below the surface. The scientific definition of a mineral as a substance of practically uniform chemical composition, of definite geometrical shape, and as formed independently of animal or vegetable life, is one that is only theoretically true, and is not substantiated by any treatise on mineralogy, nor supported by any public collection of minerals.

Thus, on the strictly scientific definition, water (snow and ice) would be regarded as a mineral, and coal, jet, amber, serpentine, etc., would be excluded.* Indeed, it has been remarked that 'water is the most abundant and most valuable mineral in Nature.'†

It follows that as there is no rigid definition of the word 'mineral,' the meaning of the term, when questioned in particular cases, must be decided in the Law Courts. It may, however, be fairly assumed, as a general rule, that by minerals in the commercial sense, 'mineral products' of more or less special economic value are to be understood, not, as has been contended, everything contained in the substance of the earth or under the soil that is capable of being worked to profit.

In this respect it will not be right to be guided by the Home Office list of the 'Minerals Raised in the United Kingdom,' for therein are included Chalk and other limestones, gravel and sand, sandstone, clay (as brickearth, etc.) as well as sundry igneous rocks. Under this definition of minerals, there would be mineral rights practically at or near the surface all over the country.

It would seem desirable to arrange the mineral products (earths, stone, metals, and true minerals) into those of general and those of special importance, and it is well to remember that these will vary in different countries, as in the case of placer deposits of auriferous gravel.

The right of mining has been held to include the right of removing the mineral which occurs or outcrops at the surface, as well as that which is found at various depths below. In regard to quarrying and mining, there is no hard-and-fast division between them. Chalk has been mined at a lesser depth than it has been quarried. Quarrying usually refers to pits and other open works, mining to underground works with shafts and levels. In ironstone and freestone districts, in the working of fuller's earth, etc., both systems are employed; so also with gold and coal.

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* See J. W. Gregory, *Trans. Inst. Mining Engineers*, 1909, xxxvii., p. 13.

† Water-Supply Paper, No. 263, *U.S. Geol. Survey*, 1911, p. 7.

Again, it has been pointed out that the question whether a mineral substance can be worked at a profit depends on the state of the market; hence 'it may be that a mineral one year is not a mineral the next.' Such a conclusion would apply to the 'coprolite beds' in Suffolk and Cambridgeshire, and other phosphatic deposits in this country, which no longer can be worked to advantage owing to foreign competition.

No line can be drawn between minerals at and near the surface and those deep below the surface. Thus china clay is worked from the surface to depths of 300 feet and more.

It would be useful to define the mineral wealth of estates as follows:

1. Minerals known to occur.
2. Those which in all probability occur.
3. Those of which the occurrence is purely speculative, as, for instance, in the possibility of Coal Measures beneath any part of Hampshire.

In these matters geological advice is necessary.

It may be convenient, as previously suggested, to classify the mineral or economic products of the geological formations into two groups:

1. General, or widespread.
2. Special, or of limited or restricted occurrence.

MINERAL OR ECONOMIC PRODUCTS.

CLAYS.—*General:* Common clay, used for brick and tile making and common pottery, as Valley and Plateau Brickearths, Boulder Clay, London Clay, Gault, Weald Clay, Kimeridge Clay, Oxford Clay, Lias Clay, Keuper Marl, etc.

Special: Terra-cotta clay, china clay, potter's clay, pipe-clay, fuller's earth, fire clay, shell marl.

SHALES.—*General:* The mass of Carboniferous, Lias, and other shales.

Special: Oil shale, alum shale.

SLATES.—*General:* The greater masses of slaty rocks.

Special: Roofing slate, slate for slate pencils.

SANDS.—*General:* Sharp-sand for mortar-making, filtering purposes, etc.; shell-sands for manure and for paths; foundry-sands.

Special: Silver-sand, glass-sand, silica 'clay,' silt for bath-bricks.

SANDSTONES.—Calcareous, siliceous, and cherty; grit, etc.

General: Building-stone, paving flags, road-metal, millstones.

Special: For scythe-stones or whetstones, grindstones, firestone, hearthstone (calcareous).

QUARTZITE.—*General:* For road-metal, etc.

GRAVEL.—*General:* For ballast, road-metal and paths, concrete, etc.

Special: Stream-tin deposits, auriferous gravels.

CONGLOMERATES.—*General:* For building-stone.

LIMESTONES.—*General:* For ordinary building purposes, lime and cement, whiting, as Chalk, Lias, Carboniferous Limestone, etc., including cement stones, nodules of flint, and nodules and beds of chert in limestones.

Special: Freestones, such as occur in the Oolites locally; stone-tiles, as at Stonesfield, etc.; marble, lithographic stone, tufa, dolomite, rotten stone (decalcified limestone).

IGNEOUS ROCKS.—*General:* For building and paving purposes, road-metal, etc., such as most granites and greenstones.

Special: Serpentine.

MINERAL PRODUCTS.—*Special:* Metals and ores of metals in lodes, veins, nodules, and beds; ochre, umber, and other materials used for pigments; bauxite, barytes, celestine (strontium sulphate), uranium ore, coal, lignite, jet, graphite or plumbago, peat, petroleum, natural gas, amber, fluor spar, gypsum, phosphate of lime, phosphatic nodules, rock salt and brine, soapstone or steatite, oilstone, hone-stone, asbestos, diatomite.

Notes on Some Economic Materials, with Especial Reference to Estates and Agriculture.

Building-stones are obtained from most of the harder rocks of all ages.

The more important freestones, sandstones, or limestones, that can be freely worked are obtained from the Secondary formations—Permian, Trias, Lias, Oolites, Lower and Upper Greensand, and Chalk (chiefly for inside work, Beer stone, etc.). It must be remembered that in all freestone areas the stone is liable to vary, inferior kinds known as bastard freestone replacing the better rock.

Slates.—The best roofing-slates are obtained from the Cambrian rocks of North Wales, but the industry is not so flourishing now owing to the more extensive use of red earthen tiles for modern villas.

In Cumberland green slates about ¼ inch thick are obtained from the Borrowdale Series.

In Scotland good slates, often with cubes of pyrites, are obtained at Ballachulish and Easdale (island), in Argyllshire.

Stone-tiles.—Stone-tiles, known as Stonesfield Slates, are worked in the Great Oolite at Stonesfield, near Woodstock; and others known as the Collyweston Slates in the Inferior Oolite Series of Collyweston, near Stamford.

Thin flags for roofing, etc., may also be obtained from the Forest Marble, Purbeck Beds, etc. Stone-tiles were used, especially in old times, but architects still favour Stonesfield Slates in some modern mansions, where the cost of heavier timbers is not an objection.

Scythe-stones, or Devonshire batts, were at one time extensively manufactured from the nodules of cherty sandstone in the Upper Greensand of the Blackdown Hills, in Devonshire. A few batts are still made.

Whetstone, known as Water of Ayr stone, has been obtained at Dalmore and Bridge of Stair, in Ayrshire.

Grindstones have been extensively manufactured from the Carboniferous sandstones near Newcastle-on-Tyne, Bilston in Staffordshire, Wickersley near Sheffield, etc.

Querns are still in use for grinding corn in the Outer Hebrides, as in the Island of Eriskay, where the double-millstone (*bràth*) is employed. The earlier form (*cnotag*) was made from a solid piece of rock, roughly hewn with a hollow for receiving the grain.* Some were formed from Lewisian Gneiss.

Millstones have been manufactured from carboniferous grits and sandstones, notably from the Millstone grit; also from Upper Greensand, Old Red Sandstone, Silurian grit, etc.

Burrstone, a hard cellular siliceous or siliceo-calcareous rock, which occurs in the Oligocene strata of the Paris Basin (*Meulières de Montmorency*), has been much used for millstones. Quartzites and volcanic rocks have also been employed for the same purposes.

Bricks.—Red bricks and tiles are commonly made from most of the great clay formations—the Permian and Triassic marls, the Lias, Fuller's Earth clay, Estuarine clays of the Oolites, Oxford, Kimeridge and Weald clays, Gault, Reading Beds, London Clay, Boulder Clay, etc. Some of the clays require the addition of sand. Brick-earths naturally adapted for brick-making occur extensively among the valley deposits of the Thames and other rivers; they are also associated with some of the Plateau Drifts. Suitable loams also occur in the Middle Lias, Kellaways Beds, Bagshot Beds, etc.

Yellow bricks are made from many of the loams; purplish-brown bricks are made at Luton; white bricks are made from the Gault at Cambridge; blue bricks, known as Staffordshire bricks, are manufactured from dark red clays in the Coal Measures, the blue colour being produced by sprinkling the bricks, before firing, with 'iron swarf' (dust of stone and iron).

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* 'Outer Isles,' by A. Goodrich-Freer, 1902, pp. 199, 424.

Sun-dried Bricks of larger dimensions than ordinary bricks have been made from loam or marl, mixed with straw or hair to prevent cracks; such bricks have been made from chalky Boulder Clay in Norfolk. The material, known sometimes as 'cob,' to which small stones are added when necessary, is used for mud walls and hovels.

Lime and Cement.—Lime for agricultural purposes is usually made from the purer kinds of limestone; the upper and middle beds of Chalk, some of the Oolites, Carboniferous Limestone (sometimes called 'Marble Lime'), etc. These limes are adapted for the heavier clayey soils. Blue Lias lime is sometimes used on lighter sandy soils.

The stronger limes are made from the more argillaceous limestones, or by admixture of clay with purer limestone. They are manufactured from the Blue Lias, some of the Great Oolite marly limestones, the Lower Chalk and Chalk Marl. These limes make the best mortar for outside work, that from the purer limestones being more suitable for inside work.

Cement, now generally called Portland Cement, is made from the Blue Lias, Great Oolite Limestone and Upper Lias Clay, Chalk mixed with Gault Clay or river mud, Chalk Marl, etc.

In the preparation of mortar good materials should be used, such as clean sharp sand, crushed stone, pounded tile or burnt clay, slag, etc., in the proportions of about 2½ to 1 of lime by bulk.

Blue Lias lime is desirable, especially in outer walls, the materials often used by the speculative builder being largely rubbish and poor lime, so that the mortar crumbles from the walls that bound the thoroughfares.

ROADS AND ROAD-METAL.

In the construction and repair of roads a knowledge of the disposition of the substrata along the routes and of the character of the road-metal are of importance.

The features of a road are indeed greatly affected by the subsoil and substrata, whether hard or soft, pervious or impervious; the geological structure effects the gradient, the dampness, firmness, dryness, and looseness of the roads. This influence, as pointed out by Mr. F. J. Bennett,* may be well observed in crossing from the North Downs on Chalk to the great valley of the Weald, across outcrops of Upper Greensand (mostly a narrow but dry belt), Gault Clay, Lower Greensand (dry sandy uplands), Weald Clay, and Hastings Beds (mixed strata, uplands).

A great deal of course, depends on the original construction of the road and the drainage, especially where springs are apt to break out. All highways, and even grassy plantation roads, should be drained.

In some parts of Ireland, as in Fermanagh, where the ground is partly peaty and partly limestone, the roads are like a 'switch-back.'

Much more attention is now given to the character of road-metal on the main roads, and the introduction of tar pavements has done much to abate the nuisance of dust.

In earlier days of the last century, when each parish attended to its own roads, using local material wherever possible, the road-metal varied much in quality. Then, too, there were more open pits and quarries than is the case now. Lias shale has been used on some of the trackways in Skye, where it is customary to take the nearest material at hand, if it can be made serviceable.

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* 'Influence of Geology on the Early Settlements and Roads,' *Proc. Geol. Assoc.*, 1888, x., p. 372, and *S. E. Gazette*, November 29, 1904.

Limestone was much used: that of the Lias and Oolites formed roads notoriously dusty in dry weather and sticky or slippery in wet weather. In one Midland district, when the dark Clee Hill basalt was introduced, to replace the Oolite with its white dust, a carrier complained that he could no longer see his way clearly on a dark night.

The Carboniferous Limestone, also extensively used, is a good road-metal, but it yields a great deal of grey or white dust.

Gravel, when used, should be subangular, as pebble-gravel does not bind well.

As regards dust, attrition tests show that the following rocks yield as a rule an increasing amount:

Quartz-diabase, porphyrite, quartzite, gneiss, diorite, flint, gabbro, andesite, granite, diabase, dolerite and basalt, limestone.

The following are some of the results of experiments:*

	Average Percentage of Loss in Dust.
Millstone Grit (quartzite) of Somerset and Gloucester	4 to 4·4
Mount Sorrel Granite	6·6
Chalk Flints	10·4
Gabbro, Guernsey	10·7
Mendip Carboniferous Limestone	19·0

According to modern systems of tar macadam,† the lower layers of a road may be made up of fairly hard limestone, sandstone, or slag, but the upper layer must be of selected stone, hard and durable, such as quartzite, diorite, or granite; the surface is then covered with fine chips of hard rock and tarred. The use of road-scrapings for filling crevices or as a binding material is condemned. Where desirable, the surface may be tarred and sanded, the object being to get a firm, smooth, and impervious surface.

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* E. J. Lovegrove and J. A. Howe, 'Summary of Progress for 1905,' *Geol. Survey*, 1906, p. 86.

† *Nature*, August 4, 1910, p. 161.

The following are among the better materials for road-mending:

Quartzite.—Hartshill Stone, Atherstone, Lickey Hills.

Granites.—Scotland, Channel Islands, Cornwall, Devon, etc.; also Stoney Stanton, Croft, and Mount Sorrel, in Leicestershire.

Syenites.—Markfield, Groby, and Enderby, Leicestershire.

Quartz-Porphyries.—Pentuan Stone (Elvan), Cornwall; Bardon Hill Stone (porphyroid).

The term 'granite' has been misapplied commercially to many hard rocks, such as the Mendip Limestone, Hartshill Stone, etc.

Basalts, Dolerites, etc. (Greenstones or Whinstones of North of England and Scotland).—Clee Hill Dhu Stone (blackstone, dolerite), Shropshire; Rowley Rag, Rowley Regis (dolerite), Staffordshire; Penmaenmawr Stone (dolerite), Carnarvonshire; Penlee Stone and St. Ives Stone, Cornwall.

Sandstones.—Carboniferous, such as the Yoredale Grit, Millstone Grit, Pennant Grit, Gannister Rock, etc.; Greywether Sandstone (passes into a kind of quartzite), known as Hampden and Denner Hill Stone in Buckinghamshire.

Limestones.—Carboniferous, Magnesian, Blue and White Lias, various Oolites, especially Forest Marble; Kentish Rag (siliceous limestone).

Gravels.—Various rough flint and quartz gravels, some with limestone pebbles.

Flint.—From Chalk and field pickings (seasoned flint).

Chert.—From Upper Greensand, Lower Greensand, Portland Beds, Lower Carboniferous.

Slag from iron furnaces is sometimes used, but it gives off an offensive odour.

Burnt Clay may be useful on light roads in clay districts.

Old trackways, known as 'ridgeways,' traversed some of the uplands and open downs; while hollow-ways characterize many of the lower lands in the South and West of England where the substrata are of a soft and sandy nature. These picturesque ways are, many of them, narrow tracks bounded by luxuriant hedges with trees, which sometimes form a kind of tunnel; and in the sandy and marly areas the slopes have become deeply excavated, as in the New Red Sandstone and Marls in Devon and Somerset, in the Midford Sands near Yeovil and Bridport, in the Lower Greensand bordering the Wealden Vale, and in the Upper Greensand near Devizes. These hollow-ways were eroded in part by the traffic of pack-horses, etc., and in part by streams which coursed along the lanes in rainy weather.

In the loess areas of China, as observed by Pumpelly, the waggon-roads have been excavated in places to a depth of 50 feet or more by the traffic and the removal of the loamy dust by winds. On hard rocks the lanes and by-roads frequently show the solid slate or igneous rock on the surface of the steeper slopes, while, as in Cornwall and parts of Devon, there are comparatively few road-side sections.

Some Ancient Workings.—Shafts have been sunk in areas where the Chalk is covered by Eocene strata, or Clay-with-flints, for the purpose of obtaining Chalk for agricultural purposes, since Romano-British times. On the higher grounds of Chalk in Buckinghamshire, Hertfordshire, and Berkshire, such shafts have been sunk 15 to 60 feet deep, when the material could be obtained from the surface on the slopes of the valleys at no great distance. It was, however, reckoned less expensive to the farmer to procure his Chalk dressing on his land at the higher level, rather than to obtain it from a distance at a low level, and in places beyond the limits of his holding. (See also p. 131.)

Shafts have been sunk through drift-sand in Chalk in Neolithic (and possibly earlier) times, for the purpose of obtaining flint, as at Grimes Graves in Norfolk, north-east of Brandon, in Suffolk, where there were about 254 pits, 20 to 65 feet deep, with branching galleries; and at Cissbury, near Worthing. At these localities the width of the shafts greatly decreased from the mouth to the bottom, and there galleries or burrows were driven in various directions. They were evidently made for the material extracted.

Shafts have also been sunk in somewhat similar situations, and probably for other purposes, as store-houses for grain, etc., and as places of refuge. They are known as 'dene-holes,' a term that is regarded as meaning Dane holes, because the Danes utilized some of them, and not den-holes.

Mr. T. V. Holmes, who has given great attention to the subject,* has described the dene-holes of Hangman's Wood, near Grays Thurrock, in Essex, where a number of shafts sunk through Eocene strata into Chalk, to depths of about 80 feet, ended in chambers, which were not connected with other dene-holes. Such an arrangement—the isolation, the number, and the small extent of the passages—in his opinion, indicated that the pits were used for domestic purposes, rather than for the material extracted.

Mr. W. Johnson has also described dene-holes as narrow shafts 70 to 100 feet deep and ending in simple or complex chambers. The majority, in his opinion, belong to the Iron Age, but some may be older, even Neolithic.† According to Mr. E. T. Newton, the mammalian remains so far obtained from dene-holes, include none of the extinct species, and do not therefore indicate great antiquity.‡

There would be an advantage, if the dene-holes were used for domestic purposes, if the Chalk were covered by any impervious deposit, as the chambers would be protected from the direct percolation of rain.

Dene-holes have also been found in the Magnesian Limestone of Durham.

The subterranean storage of grain was a practice dating back to Romano-British times, and Mr. Holmes has called attention to their use in Brittany, India, and South America, at the present time.

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* *Essex Naturalist*, 1887, i., p. 225; 1907, xv., p. 10; *Geol. Mag.*, 1898, p. 447.

† 'Folk-Memory,' 1908, pp. 234-239.

‡ *Proc. Geol. Assoc.*, 1908, xx., p. 462.

On Kingbarrow land, Portland, some beehive-shaped cavities, 7 to 9 feet deep, were discovered by Mr. A. M. Wallis in the Purbeck strata overlying the Portland Stone; they were built up of thin, flaggy stone, and covered with slabs, and had evidently been used for storing grain. Rock granaries or grain-pits have also been found in Norfolk and elsewhere.

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[Many of these names are of considerable geological interest, as they give ndication of the substrata, springs, plants formerly cultivated, etc.]

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CHAPTER XVI

SITES FOR HOUSES—DISPOSAL OF WASTE WATER—FARM DRAINAGE AND REFUSE —SEWAGE FARMS—CEMETERIES —WATER-SUPPLY AND PONDS

WHEREVER a choice can be made of a site for the building of a house, or of one where houses have already been constructed, there are numerous matters that require consideration. In the selection of a fresh site for building, the matter of prime importance is to ascertain if a good supply of potable water can be obtained at a reasonable cost, whether from water company, well-boring, or spring. In the selection of a house ready for occupation the nature of the water-supply is again a first consideration, especially in country places, where the supply may be purely local from well, boring, or spring, with the possibility of contamination from imperfect sanitary arrangements. Again, the supply of hard or soft water is a matter of concern to some individuals, although statistics show that the general health in towns is not affected by such waters.

Concerning the soil and subsoil, since a dry and well-drained situation is desirable, a foundation on sand, sandstone, gravel, Chalk or other limestone, is, as a rule, to be preferred to one on clay, shale, or loam of impervious nature. The really important matter here is the subsoil; the actual soil has importance only in connection with the garden, where naturally a fairly light and deep loam or gravelly loam is to be desired.

The subsoils, before mentioned, of sand, sandstones, etc., are of a pervious nature, and therefore the rain-water descends below the surface through the loose materials, or through cracks and joints; but the subsoil to be dry and healthy must be of sufficient thickness and at a sufficient elevation to permit of the water descending below the level of the foundations of the house.

Here the form and geological structure of the ground have to be considered, because in certain situations all these pervious formations may be wet and unhealthy.

In low-lying situations bordering a stream or river, Chalk, gravel or other pervious formation may be water-logged, especially when the river is swollen after heavy rain.

At higher elevations a bed of gravel and sand may spread over a considerable area, but be of such limited thickness, 3 to 5 feet, overlying clay, that the ground-water may at times be within a foot or two of the surface. In such cases the underlying clay has often an irregular surface, so that, although on the margin of the plateau water will escape in springs, underground sheets or pools of water will remain here and there, and basements of houses may be damp.

The writer was informed by T. Mellard Reade that the only safety is to seal up the whole area of the buildings, whatever the subsoil. He had found the dry-rot in floors where the Triassic Red Sandstone came to the surface, and where an air space (ventilated) was left under the floor; while in another case a building on Boulder Clay under the same conditions was free from dry-rot. The fact was that the damp rose in the sandstone by capillary action.

These remarks apply to all thin cappings of sand, sandstone, gravel, or limestone, that overlie clay on a fairly level upland. An examination of the bordering slopes will generally indicate the base-level of the ground-water where it issues either in definite springs or in seepage. If the strata are inclined, springs may be given out along one side of an elongated hill, but not on the other, as may also be noted in some railway-cuttings.

Where the strata are inclined, and the pervious beds are intercalated between clay or shale, the pervious subsoils will again be liable to be water-logged, or the ground-water may rise at times to near the surface.

The higher portions of some Chalk valleys that in summer time are dry are occupied by streams or bournes after long-continued wet weather. Such sites should be avoided for building. In some localities very fine-grained sands do not allow rain to sink readily, and the ground remains sodden for some time.

Many villages were founded on tracts of pervious limestone, gravel, or other subsoil, because water was readily obtained by shallow wells. In course of time, owing to defective sanitary arrangements, the subsoil has become polluted, the wells have been condemned, and fresh sources of water-supply have to be sought. Irrespective of this, the uprising of ground-water after heavy rain is apt to drive foul air with noxious germs from the soils to the surface. A site on unpolluted pervious strata should therefore be selected.

Early Settlements.—It is well known that prehistoric works of man characterize many of the open downs and wolds, from East Yorkshire and Lincolnshire to the Cotteswold Hills, Marlborough Downs, Salisbury Plain, Cranborne Chase, and the downs in South-Eastern Counties. They are also abundant on Dartmoor. In such areas, as remarked by J. R. Green, 'we find traces of early culture and of the presence of a population which has passed away as tillage was drawn to richer soils.'*

The nature of the substrata, as well as of the soils, influenced many of the final settlements, because, where pervious formations rested upon clays, their junctions along hill-slopes were marked by springs, and these led to the fixing of sites for habitations and the growth of villages. Other settlements were made near the open courses of streams and rivers.

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* 'The Making of England,' 1881, p. 10.

Among the Secondary formations, the villages and towns stand on or near the Lower and Middle Lias limestones, or the sands and limestones of the Oolitic and Cretaceous Series ; while the clay vales, unless where covered with river or other drift gravel and sand, were, and still are in many instances, but thinly populated. This was the case also among the Tertiary strata on the expanses of London Clay until deep artesian wells supplied water in abundance, and again on the more elevated Chalk uplands, which could not become residential sites until water companies supplied their needs.

Topley remarked in reference to the South-East of England that everywhere along the foot of the Chalk escarpment there is a line of villages, mostly on the Upper Greensand, and that in nearly every case the *parishes ascend the escarpment*, generally taking in a good deal of the tableland above, but occasionally ending off at or near to the crest. In other directions they extend over the Gault, and in some cases over the Lower Greensand. The parishes are comparatively narrow in proportion to their length up and down hill.

He considered that early settlements were made along the wider Chalk valleys and along the foot of the escarpments, where good water could be obtained from the Upper Greensand or the lower beds of Chalk (above the Chalk Marl), where the productive soil of the Upper Greensand, etc., could be cultivated, and where the situations were sheltered. He concluded that, in the subdivision of the ground, the settlers would arrange for a certain amount of Chalk down for sheep, of good arable land, and of forest for swine, etc. Hence arose the disposition of the parish boundaries.*

In the more extensive vales of clay or shale there is generally more moisture in the atmosphere, and more liability to mists, than on the breezy uplands, although all areas are subject at times to mist. Such clay lands, however, form undulating ground rising into hills sometimes 300 feet in elevation, and as the hilly tracts are for the most part naturally drained, a site on ground of that character would be preferable to one on a pervious formation subject to a rise of ground-water too near the surface.

On hilly ground the surplus rain, after moistening the clay, runs off the surface. Clay, indeed, absorbs a lot of moisture (see p. 110), whereby it becomes swollen, whereas in dry weather it shrinks, and great cracks, a yard or two in depth, may traverse the ground. On this account buildings are sometimes subject to irregular settlements that cause cracks, while garden-walls become fissured and inclined.

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* 'On the Relation of the Parish Boundaries in the South-East of England to Great Physical Features,' *Journ. Anthrop. Inst.*, 1873, iii., p. 32.

In an article recently published, it was stated that 'it is impossible to estimate the enormous damage that has been done to buildings throughout the country by the excessive spell of hot and dry weather experienced last summer.'* Under ordinary circumstances clay may retain much moisture, even in summer time, at depths of 2½ to 3 feet from the surface; but in 1911, in the suburban metropolitan area, the London Clay was frequently found to be perfectly dry at depths of 5 and 6 feet. Hence shrinkage of the subsoil, which takes place both vertically and horizontally, causes so much injury to buildings. The facts indicate 'the importance, firstly, of obtaining a sufficient depth of foundation to reach below the point affected by sun and rain, and, secondly, of carrying all foundations to a uniform depth.'

In the heart of London the ground is so much covered with buildings and paving materials that a comparatively small amount of water now passes into the subsoil, most of it being directly conducted into the drains, which are the subterranean courses of many an old stream. In such parts of London it is often difficult to ascertain the nature of the subsoil, whether gravel or sand, brickearth, or London Clay, as in old times there were many gravel-pits and brickyards; the clean earth was removed, and the pits were filled with rubbish or 'made soil.' Building on such sites is happily no longer permitted by the Local Government Board until the offensive materials have been removed, or have been rendered innocuous by natural changes during the course of some years. Consequently, in London, aspect, elevation, and surroundings are more important than subsoil.

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* *Builder*, January 5, 1912, p. 16.

The construction of the house is another highly important matter, especially with regard to good cemented basements, and to damp-courses to prevent the uprising of moisture from the soil through porous brickwork or stone to the ground-floors. An insanitary house may thus be found on a good site and *vice versa*.

It is desirable to select ground where a formation of fairly uniform character extends over a considerable area. On a gentle slope, or in other situations, the junction between two formations of different lithological character is to be avoided, especially if marked by springs, as the ground would be unstable and liable to landslips. Again, in some tracts of Chalk and other limestones the piped or furrowed surfaces occasionally lead to subsidences (see p. 64); and similar catastrophes occur in tracts where salt or coal have been mined. Where the strata are known to be much disturbed or faulted, the ground, again, might be unstable.

The characteristic features of land and village form interesting studies on long railway journeys, and the traveller may note such points as the following:

Limestone areas rise generally into uplands, with often bold escarpments, and they possess few streams on the higher tracts, where the strata are of considerable thickness, as the water sinks to approximately the level of that running in the valleys. Short sweet herbage grows on the Chalk and Carboniferous Limestone, but there is much arable land on the brashy Oolites and Lias Limestones; stone-built houses, often with stone tiles and stone fences, are usual on the Oolites and older limestone areas, while the beech, ash, box, holly, juniper, and yew flourish in many places.

Sands and gravels form fairly level tracts both of upland and lowland, with arable lands and much heath and common, where the Scotch fir, gorse (furze or whin), broom, heath, heather or ling, bracken, and whortleberry thrive.

Clays form as a rule low and gently undulating country, with many streams and ponds, with much meadow and pasture, arable land with wheat and beans, good hedgerows, with many oaks and elms, also hornbeam, etc. Brick-built houses with slated roofs prevail.

The alluvial or marsh-lands are often liable to floods, and, where not artificially drained, are characterized by reeds, rushes, sedges, bog-moss, cotton-grass, with also willow, alder, and poplar.

The terraced strips on hillsides, which are termed 'lynchets' or 'lynches,'* are noticeable features in the landscape of the Chalk Downs and of certain particular districts. Notable examples occur between Cambridge and Hitchin, near Luton, on West End Hill by Cheddington in Buckinghamshire, along the Chiltern range, at Binks Banks near Lambourn, on the Marlborough Downs, near Calne and Devizes, on Salisbury Plain, near Market Lavington, Warminster, Mere, and Hindon, near Shawford Station south of Winchester, and on the Sussex Downs.

They are conspicuous on the slopes of the Portland and Purbeck Beds in the Isle of Purbeck (see Fig. 11), and may be seen on the Corallian rocks in Dorset, near Gillingham, and to the west of Abbotsbury. They occur on the Inferior Oolite and sands of the Cotteswold Hills, Brent Knoll and Glastonbury Tor in Somerset, and near Bridport in Dorset. (See Fig. 12.) They may be observed on scarps of the Middle and Lower Lias in Leicestershire, as on Tilton-on-the-Hill; in Northamptonshire; in Oxfordshire, as at Rattlecombe Slade, Shenington, north-west of Banbury; also in Somerset, between Litton and Chewton Mendip, and in Dorset, near Bridport.

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* The spelling of the words applied to terraces of cultivation varies much—thus linch, lytchet, linchard, lanshet, etc.; and it has been suggested that the name 'links' is of similar derivation. The term 'reans' or 'reins' is applied in the North of England and Scotland, and that of 'ridges' or 'butts' in Wales.

But their real origin has been the subject of much speculation, F. Seebohm* attributing them to the gradual moving of the sods downwards by the share as the horizontal furrows were ploughed, and finding in them a permanent record of the 'open' or 'common-field' system of cultivation; while Sir G. L. Gomme maintains that they were cut and, in many cases, banked up by retaining walls or stone facings in much more primitive times.† Dr. H. C. March (1903),‡

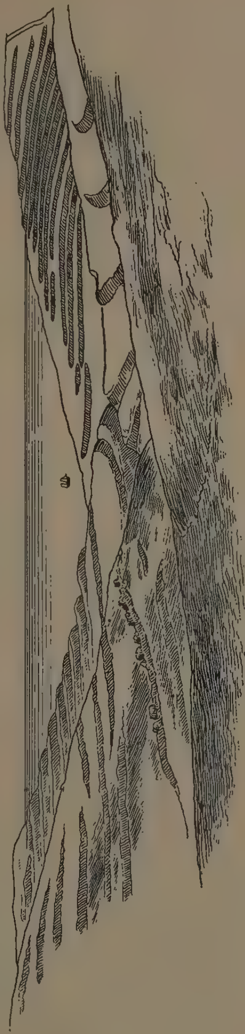

FIG. 11.—VIEW OF LYNCHETS, NEAR WORTH, ISLE OF PURBECK.
(From an etching by Alfred Dawson.)

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[*] 'English Village Community,' 1883, pp. 3-6. See also G. P. Scrope, *Geol. Mag.*, 1866, p. 293.

[†] 'Village Community,' 1890, pp. 80, 90, 95. See also F. J. Bennett, 'A Sketch History of Marlborough in Neolithic Times,' 1892.

[‡] 'The Problem of Lynchets,' *Proc. Dorset Nat. Hist. Club*, 1903, xxiv., p. 66.

on the other hand, has seen no lynchets in Dorset that possess any retaining wall. Near Portesham he observed 'some remarkably flat ledges, now in pasture, that correspond with alternate beds of nodular rock and Portland Sand. The formation of terraces was thus favoured, and their outer edges, where the soil has accumulated, indicate a former cultivation.'

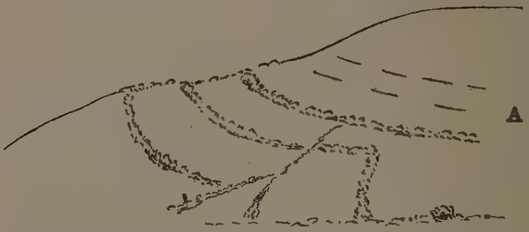

FIG. 12.—HILL NORTH OF BOTHENHAMPTON, DORSET.

In this rough sketch the higher grounds, formed of Inferior Oolite, were early under cultivation, as indicated by lynchets (A); on the lower slopes hedgerows are growing on the underlying Midford (or Bridport) Sands; these conform to a certain extent with the lynchets, and might indeed give rise to terraces if the hedges were removed.

Artificial terraces, somewhat resembling lynchets, were pointed out to the writer in the Stroud Valley by J. H. Taunton, who stated that they were used in old times as racks for drying cloth.

DISPOSAL OF WASTE-WATER, FARM-DRAINAGE, AND REFUSE.

Dumb-wells (absorbing or blind wells) and percolating cess-pits for waste-water and house-drainage must not be constructed in situations where the water-supply of the area is liable to be affected, least of all where the underground strata are rocky and fissured.

It should be borne in mind that when injury is done to neighbours or neighbouring works by defective drains or other cause that can be proved, compensation may rightly be claimed.

Quite recently Dr. H. Franklin Parsons had occasion to remark that 'several important Kentish towns still remain unsewered because the facility for disposal of sewage afforded by cesspools leaking into the porous chalk appears to their inhabitants to render the cost of sewers unnecessary.'

Ash-pits and privies should be well cemented or asphalted to prevent leakage, and they should be roofed and ventilated.

Farmyards inevitably are more or less fouled by accumulation of muck. In some cases the natural rock protrudes here and there over a sloping tract of ground, or the yard is paved with irregular flagstones or cobbles, and muck accumulates in hollows and crevices. It is essential that the drainage from such yards, as well as that from stables, cow-sheds, etc., be so conducted away that wells or springs used for household and dairying purposes be not contaminated. Dr. Somerville recommends that 'the floor of the dung-heap should, as far as possible, be impervious to the passage of liquids, nor should liquids be allowed to flow away from the mass, unless they can be led into a suitable tank.' *

On some tracts of pasture-land there are old pits and quarries, or swallet-holes in limestone-rocks, that are liable to be fouled by cattle, whereby the underground supply of water may be polluted.

In many a village the public 'dust-bin' is situated in some old pit or hollow, adjacent to the parish well, or to that used by one or more of the villagers. To shoot rubbish in such situations is most culpable. (See Figs. 13 and 14.)

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* *Agriculture*, 1912, p. 183.

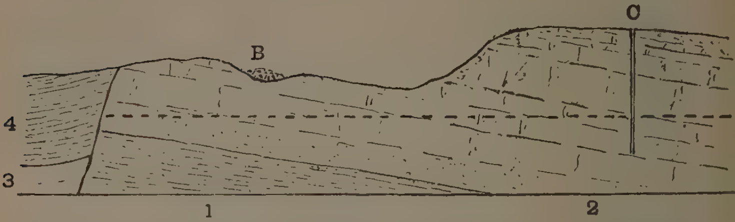

FIG. 13.—SECTION SHOWING WELL-WATER LIABLE TO POLLUTION FROM PARISH DUST-HEAP.

4, Kimeridge Clay. 2, Corallian Sands.
3, Corallian Limestones. 1, Oxford Clay.

A, Approximate plane of saturation or water-level.
B, Rubbish heap. C, Well.

Here we find a well supplied with water from strata worked for building-stone in a quarry, the abandoned part of which, about 200 yards distant from the well, is utilized as a receptacle for the village refuse.

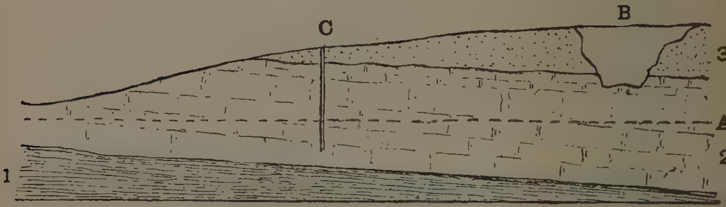

FIG. 14.—SECTION SHOWING WELL-WATER LIABLE TO POLLUTION FROM PIT USED FOR RUBBISH.

1, Kimeridge Clay. 2, Portland Limestones. 3, Lower Greensand.

A, Approximate water-level. B, Old pit used for rubbish.
C, Well.

Here again a pit in pervious strata, from which supplies of drinking-water are drawn, is used as a kind of dust-bin.

Where parishes cannot afford a dust-destructor, it may be necessary to utilize some artificial excavation ; but this should be selected at a distance from public roads and footpaths, and not be in pervious strata, where there is a possibility of contamination to sources of water-supply. The 6-inch Geological Survey maps should aid local authorities in fixing sites for such purposes. Here it may be mentioned that an experimental area of about 200 acres, known as the Murieston Estate (by New Park Station, on the Caledonian Railway, and about thirteen miles south-west of Edinburgh towards West Calder), has been used by the Edinburgh Distress Committee for the disposal of house refuse, manure from stables and cow-sheds, street sweepings, etc.

The ground is formed of Boulder Clay over Lowe Carboniferous Shales, etc., and one object is to convert the land into market-gardens.

One thousand loads per acre have been deposited on some plots, 12 to 18 inches below the surface, and covered with about 8 inches of earth, old turf, etc.

The proceeding so far has not been a commercial success, but has proved 'far more remunerative' than other schemes tried for the benefit of the unemployed.*

SEWAGE FARMS.

Sewage farms constructed to deal with the drainage by irrigation after solid matters have been strained out, are best situated on large tracts formed of porous strata, where there is a good top soil, suitable for the development of bacteria. Gravel and sand overlying clay in a valley may be adapted for the purpose when the pervious strata are not utilized for water-supplies, and where they rise well above the level of the river. The strata should have a general inclination towards it, so that the deposits are not water-logged, while the land should not be liable to floods. Areas of Blown Sand may be suitable, whereas clays are not so. The Chalk as a rule is undesirable.

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* W. Smith, of Edinburgh, in 'Report of Royal Commission on Coast Erosion,' 1909, vol. ii., part ii., p. 372.

Modern systems of dealing with sewage by artificially-constructed bacteria beds, whereby putrescible matters are converted into harmless and inoffensive products, render it possible to discharge the effluent without further treatment directly into a river.

Care must, however, be taken to ascertain that the effluents do not flow over pervious strata that are utilized for purposes of water-supply.

Rye-grass and osiers are considered the more suitable crops on sewage-farms.

CEMETERIES.

Sites for cemeteries have to be selected with due regard to neighbouring populated areas, and in particular to wells, borings, and other sources of water-supply. It is reckoned that about one acre per 1,000 of population may be sufficient for a period of fifty years.

Hard rocks, with shallow soils like the Carboniferous Limestone, are objectionable on two grounds; graves may have to be blasted out, and there is a liability to pollution of water-supply. Sites on Chalk, again, have to be selected with great care, on account of the many water-works on that formation.

Low-lying gravel areas, and those otherwise liable to much rise in the ground-water, are not suitable, as a rule, for graveyards. Stiff clays, like the London Clay, are objectionable on account of the fissured surface of the ground in dry weather; in wet weather, also, the fresh open graves may hold much water. A light loam, or sandy and gravelly loam, is regarded as the best sub-stratum, preferably 10 feet or more in thickness; indeed, in the case of large cemeteries, a depth of 20 or 25 feet is desirable. Sands and gravels are suitable as substrata, if the ground water-level is at least 2 feet below the level to which graves are dug. Deep drainage may in some cases be necessary. More or less isolated upland tracts are to be preferred as sites for cemeteries.

In the matter of sites near springs, it must be observed that the underground water, from the overflow of which the springs are fed, may be affected by burials. Thus on escarpments there is usually a dip away from the valley where springs break out. The springs overflow from a water-bearing limestone or sandstone, but there may be an underground flow in the pervious strata along the dip, if water is pumped from wells, or there is any natural exit in that direction.

It is impossible to say to what distance contamination may be carried, but very much depends on the nature of the strata. With hard-jointed limestones and sandstones there is no particular limit. With very fine sands, or loamy or calcareous sands, good filtration probably takes place in the course of about 100 yards.

WATER-SUPPLY AND PONDS.

The question of water-supply has been dealt with in a companion volume,* wherein rain-water, shallow and deep wells, and borings, are considered.

Water may be raised by ordinary pumps from depths not exceeding 30 to 33 feet; by windlass and bucket from much greater depths. It may be raised also by windmill, or by means of an hydraulic ram, from a stream, which may require a dam to produce the necessary fall to work the machinery by which the water is raised.

For particulars relating to underground waters for farm use, see a paper by Mr. M. L. Fuller, named among the references at the end of the present chapter.

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* H. B. W., 'The Geology of Water-Supply,' 1910.

It may be mentioned that the proprietor of the land has full power over underground water that is not in a defined channel or stream, and to stagnant water. The natural rights in water-courses are commonly known as 'riparian rights.'

Special supplies may be needed for agricultural purposes, especially on dairy-farms.

On elevated tracts of down-land, as on many parts of the Chalk, and on the Oolites of the Cotteswold Hills, the ground-water may be at a considerable depth, 100 feet or much more, too deep, on account of expense, for the supply of water-tanks. Limited supplies are obtained in places where the Chalk is covered by Clay-with-flints; elsewhere rain-water tanks may be necessary, unless supplies can be had from water companies. Water at high levels on porous strata may be collected from concreted surfaces or galvanized corrugated iron.

Dew-ponds situated on the Chalk Downs far above the plane of saturation in the Chalk in some instances may date back to Neolithic times.* Others have been constructed at various periods up to the present day.

Many have been constructed on spurs of Chalk hills, and there, as pointed out by Mr. F. J. Bennett, they may receive some of the drainage from the ground at higher levels. Moreover, the ponds are said to attract the mists, which are denser and more frequent at these high elevations than in the low grounds; and the rain and snow fall are also greater. The ponds vary from 30 to 45 feet in diameter, the bottoms are puddled, and some have never been known to fail. Many modern ponds are cemented. Mr. Bennett adds that '1,000 sheep have been daily watered from some of them in seasons of drought.'*

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* 'Neolithic Dew-ponds and Cattle-ways,' by A. J. and G. Hubbard, 1905.

The recent researches of Mr. E. A. Martin confirm the view that dew-ponds apart from the rain and snow fall are mainly fed by mists.†

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* *Proc. Geol. Assoc.*, 1888, x., p. 372.

† *Geograph. Journ.*, 1909, p. 174.

CHAPTER XVII

GEOLOGICAL FORMATIONS, WITH ESPECIAL REFERENCE TO ENGLAND AND WALES.

I. QUATERNARY OR SUPERFICIAL DEPOSITS (RECENT)

The formations included as Quaternary represent various deposits laid down during the later geological periods, when the past and prehistoric, so far as man is concerned, merged into the historic and present.

The term 'superficial deposits' is generally appropriate, although older formations form much of the actual surface of the ground; but these newer accumulations are not ranged in the regular order that applies to the Tertiary and older strata. In those formations are represented more local phases of the deposits of sea, estuary, or river, and less often the purely terrestrial accumulations. The superficial deposits include all manner of accumulations of sea, estuary, river, lake and glacier, with some that were wind-drifted and others chemically deposited. Moreover, they occur at various elevations from the deep valleys to considerable altitudes on fells and mountains, and some of them rest directly on all the earlier formations, stratified and igneous. Although the method of origin of various superficial deposits is dealt with in the following pages, their relative ages are not discussed.

The thicknesses of formations vary so much in different localities, in part from original deposition, in part from subsequent erosion, that it will be sufficient generally to refer to the table, p. 10. Where special information is required, reference must be made to the Geological Survey memoirs and maps. (See p. 349.)

Alluvium.

The alluvial or bottom lands, which form the flat ground bordering rivers, are most largely composed, near the surface, of fine materials, clays, marls, loams, sands, and silts, with peaty tracts, areas of shell-marl, tufa, and sometimes diatomaceous earth. Gravel likewise occurs in seams among the other strata, in some places forming the surface in irregular patches, as in the Trent Valley near Nottingham, and elsewhere, as along the higher river-courses, constituting the main mass of the alluvium.

The subsoil along a river-valley may be as varied in the case of a small river as in that of a large one. The actual soil is, however, mostly fine, deep, of varied composition, and productive both as grass and arable land, excepting in the wet, marshy, and peaty grounds, since the fertility depends on the freedom from stagnant water.

Most river-valleys, unless protected by artificial banks, are liable to floods after long-continued and heavy rain, or the rapid melting of snow, as in the case of the Thames, Great Ouse, Nene, Severn, etc.; but in the broad, alluvial flats of Sedgemoor and the Fenland there are some areas of marsh-land that, apart from the effects of artificial drainage, were not originally subject to ordinary floods. The levels are divided by ditches or water-courses, known as 'rhines' in Somerset, 'reens' in Monmouthshire, and 'lodes' or 'dykes' in the Fenland.

In clayey districts it is sometimes difficult to define the respective areas of the clay, such as the Lias or Oxford Clays, and the alluvium, as on the borders of Sedgemoor, and in the Ot Moor district near Oxford. The low, clayey ground passes imperceptibly into the alluvium, which itself is formed largely of clay. In some parts of the Brent Valley, in Middlesex, it was difficult to distinguish London Clay from the alluvial clay derived from it —unless an intercalated seam of gravel occurred in the alluvium.

In areas of Triassic red sandstone and marl the alluvium is a red loam or sandy loam, as in Devon and Somerset, where the river deposits are far more fertile than those brought down from the shales and sandstones of the comparatively barren Culm Measures.

The occasional flooding of alluvial meadows and grazing grounds is advantageous, if the water does not lie long, and the ground is fairly pervious; the land thus receives a fertilizing film of fine earth, with organic matter, much of it soil washed from adjacent land surfaces. Frequent flooding and long-standing water are apt to be injurious.

Low hills or mounds often occur in alluvial tracts, and it is difficult to ascertain their geological nature from surface evidence. In the estuarine and alluvial tracts bordering the Forth and Tay in Scotland there are certain elevated mounds or ridges of clay-loam, locally known as 'black land,' which at one time rose as islands or 'inches.'

Professor T. McKenny Hughes drew attention to mounds that occur in the marsh-lands bordering Sheppey, which might be attributed to tidal action and the modifying effects of subaerial denudation. Others appear to have been artificial, like the 'Red Hills' on the Essex coast, near Fambridge, Burnham, Maldon, and St. Osyth. They comprise low mounds, varying in size up to several acres, and appear in many cases to have been burnt to a red colour. No definite explanation has been given, but they have been regarded as possibly cattle-shelters, or the refuse of potteries, salt-works, or glass factories. At present the Exploration Committee of the Essex Field

Club have been unable to endorse any of the theories regarding the origin and uses of the Red Hills.*

The flats bordering estuaries are made up of tidal alluvium, or silt, and are known as 'salt marshes' or 'saltings,' when liable to be flooded regularly or occasionally at high-tide.

Salt marshes occur along the lower Thames Valley, in Essex near Walton-on-the-Naze, in Norfolk near Holkham, Wells, and Blakeney, in Glamorganshire along the estuary of the Loughor or Burry, north-west of Gower, and in other localities.

The alluvial flats of the Severn drainage, along the borders of the Bristol Channel, in Somerset, Gloucester, Monmouth (the 'Moors'), and Glamorgan, are largely estuarine mud, which gives rise to excellent grass-lands.

Thus it is that the alluvial grounds of rivers and estuaries include some of the richest grazing-lands, especially for cattle, in this and other countries.

In an interesting essay 'On the More Important Breeds of Cattle which have been recognized in the British Isles,' Professor T. McKenny Hughes† pointed out that among the ox tribe the bison (*Bison priscus*), found in Pleistocene (Palæolithic) deposits, became extinct in Britain before Neolithic times, and that the urus (*Bos primigenius*), which appeared in Palæolithic times, characterizes the Neolithic Age, and probably did not become extinct until the Bronze Age. 'In England no bones which could possibly be referred to the urus have been proved to have been found with Roman or later remains, and no evidence has been obtained of its having ever been domesticated in this country.'

On the other hand, the Celtic short-horn (*Bos longifrons*), which appeared in Neolithic times, lived on during Roman times and after; and it 'is the native breed with which we must start in all our speculations as to the origin and development of British oxen.' This view is supported by Professor James Wilson.‡

Professor Hughes further brought forward evidence to show that 'the Romans improved the Celtic short-horn by crossing it with cattle imported from Italy,' and thus of the modern representatives the Kerry cattle are the most typical examples of the Celtic shorthorn, the Chillingham cattle being nearer to the Roman ox. The Highland and Welsh cattle are forms more or less modified by the Roman breed. All these cattle are whole coloured or shaded.

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* See *Essex Naturalist*, 1906, xiv., p. 170; 1907, xv. (Appendix).

† *Archæologia*, 1896, lv., p. 125.

‡ 'The Evolution of British Cattle,' 1909.

The long-horns, 'which appear nowhere with Romano-British or early medieval remains, are the offspring of larger breeds imported from Holstein and the Low Countries in later medieval times.' These and subsequent introductions are variously coloured, little or no attention having been given to the subject in breeding.

Remarks have sometimes been made on the colours of cattle in reference to soil, especially with respect to the red cattle of Devon, and the red and white faced cattle of Hereford; but Mr. H. Tanner has stated that the West of England oxen were originally red when introduced, and that the Hereford breed with white faces was established about the middle of the eighteenth century.* According to Professor J. Wilson, the red cattle came with the Anglo-Saxons.

Pevensey Level, in Sussex, which is protected from the sea by a shingle bank, affords famous pasture for cattle. On the other hand, Romney Marsh, in Kent, but with bordering levels in Sussex, is given up chiefly to sheep. A good deal of the land there is below high-water mark of spring tides, and it is protected by a sea-wall at Dymchurch and by the shingle of Dungeness. The Dowles, near Appledore, is 13½ feet below the highest water-level. The soil, peaty in places, is for the most part a fine and rich clayey loam, with sea-sand in places. The land is drained by ditches, which discharge their waters into streams called 'guts.'

Passing on to other large tracts of alluvium, we come to the great area of the Fenland, including in the south the Bedford Level, which, with the Soke of Peterborough, extends to Wisbech, Downham Market, Mildenhall, Ely, and Ramsey; while in the north are the Fens of Holland, in Lincolnshire, extending south of Wainfleet and Tattersall to Spalding, etc., and deriving the name from the fact that the works of drainage and reclamation were carried out by Dutch engineers. The Fenland area consists to a large extent of marine silt of great fertility, with also river mud, and much land is under arable cultivation for corn, roots, potatoes, and celery.

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* *Bath and West Eng. Agric. Journ.*, 1858, vi.

There are tracts of gravel (of older date), as at March, Chatteris, and Whittlesey, and large areas of peat-land.

The alluvial flats bordering the Humber and tributary rivers in Yorkshire and Lincolnshire consist of peat, tidal alluvium, silt or warp, lacustrine clay, marl, loam, sand, and gravel—altogether from 25 to 90 feet thick.

The peat* is sometimes 20 feet thick, and it becomes consolidated when warp is introduced artificially over it. It forms black or brown lands, and, near Thorne, owing to the number of trunks and stumps of trees—chiefly oak—that occur in it, a good deal of expense was incurred in preparing the land for cultivation. The tree-trunks were occasionally used as gate-posts, while some of the wood was converted into charcoal for use as manure.

In Holderness, as described by Mr. C. Reid, there were formerly a number of meres, all of which, like many in the Fenland, have now been drained, except Hornsea Mere. They have given rise to irregular tracts of clayey and peaty alluvium or 'moorlands,' as they are locally termed. There are also many 'cars,' originally swampy alluvial tracts bordering streams, some covered with alders and willows forming fen-woods, but most of them now well drained. These areas have been largely converted into pasture-land, although, as Mr. Reid remarks, the water is brackish, and therefore unfit for stock.† The warp-lands form the best and richest soils. These areas, like those of the Polders of Holland, and Flanders in Belgium, have been formed by the process of warping on land reclaimed from the sea and embanked, the Polders being the tracts successively secured.

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* As noted by Mr. A. C. G. Cameron, 'Geology of North Lincoln,' *Mem. Geol. Survey*, pp. 152, 153.

† 'Geology of Holderness,' *Mem. Geol. Survey*, 1885.

The warp of the Humber has been utilized, since the seventeenth century, over the marshy and peaty areas bordering the river below the level of high tides, but the process was not generally practised in Lincolnshire until the latter part of the eighteenth century. The material consists of fine sand and clay, which subsides at different rates, so that a laminated deposit results. Three or four feet of rich warp may be deposited in two or three years.*

The process of warping is carried out along the tidal and embanked portions not only of the Humber, but of the rivers which flow into it. The incoming muddy tidal water is introduced through sluices or flood-gates from the river-banks on to embanked areas of land, sometimes a mile or two from the river, and drained off slowly at low tide.

In composition the warp was found by J. D. Sollit to be as follows:

	Per Cent.
Fine sand	70 to 80
Alumina	4 to 13
Carbonate of lime	2 to 6
Carbonate of magnesia	0 to 2
Soluble salts	2 to 5
Oxide of iron	1 to 3
Organic matter	4 to 7

The silt in the Humber amounts to more than that known in any other British river. According to Mr. C. Reid the material is derived from the Drift deposits along the Holderness coast, partly carried up the Humber, and partly deposited in the Wash.†

Mr. Cameron has remarked that the warp in general is a brown and grey loam and clay, some areas forming strong and others lighter land. The natural or alluvial warp of the river is not to be distinguished from that artificially introduced. The deposit is about 18 feet thick at Brough, west of Hull, and the land bordering the river slopes gently from the banks to the alluvial flats.

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* Dr. H. F. Parsons, *Proc. Yorks Geol. and Polyt. Soc.*, 1877, 2nd series, vi., p. 214; A. C. G. Cameron, 'Geology of North Lincoln,' *Mem. Geol. Survey*, 1890, pp. 154, 155; A. R. Empson in 'Report of Royal Commission on Coast Erosion,' 1909, vol. ii., part ii., p. 114.

† 'Geology of Holderness,' *Mem. Geol. Survey*, 1885, pp. 105, 106.

The process of 'dry warping,' or the carting of warp, is applied to low elevations not reached by the flood-waters. By these means considerable tracts of more or less peaty land have been converted into rich agricultural ground, which has maintained its fertility for thirty or forty years. Wheat, oats, beans, hemp, flax, mustard, have been cultivated, as well as potatoes, more especially on the lighter warp. In the Isle of Axholme* there are many acres of warp land, partly natural, partly artificial.

Peat.

Peat is formed by the growth and decay of plants in boggy or marshy areas where the water is stagnant, some tracts being due to the growth of vegetation in meres or in deserted river-bends (ox-bows). Peaty islands formed of drifted masses of vegetation occur in some lakes; and 'flow-mosses' have been formed by the transport of peat by streams.

Peat is formed generally on a foundation of clay or shale, and attains a thickness in places of 50 feet or more. Some of the more abundant plants are:

Bog-moss (*Sphagnum*).
Feather-moss (*Hypnum*).
Cotton-grass (*Eriophorum*).
Heather (*Calluna erica*).
Bull-rushes (*Scirpus*).
Rushes (*Juncus*).
Reeds (*Arundo*).
Sedges (*Carex*).
Grasses.

The growth of peat is aided by bacteria. It is sometimes made up almost wholly of plant remains, but is usually more or less earthy, the ash amounting from 1 to more than 60 per cent., and being composed of sand, clay, iron oxide, lime, magnesia, potash, and soda.

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* J. A. Clarke, *Journ. Roy. Agric. Soc.*, 1852, xii., p. 286.

Peat is occasionally formed by marine plants, as, for example, laminaria (seaweeds). Such a bed 6 inches thick was observed by J. Lomas in Union Dock, Liverpool.*

Although peat is formed chiefly in temperate regions, peaty accumulations may arise in tropical countries by the decay of vegetation in swamps, such as the mangrove swamps commonly met with in tropical countries.

In the United States there are certain marine marshes; those above mean tide being known as mangrove swamps, and those below as eel-grass areas. The Great Dismal Swamp on the borders of Virginia and North Carolina, and other swamps along the coast, occur on higher grounds, with streams running from them. Where drained and cleared, they have been transformed into good farming-land, and there are extensive fruit and vegetable gardens.†

Peat is sometimes divided into lowland, marsh, or bog peat, formed in stagnant pools, and more or less rocky basins; and hill or mountain peat, which is formed at various higher elevations.

Lowland Peat includes the more extensive tracts in the marsh-lands and vales.

'The terms 'peat-moss,' 'turf-bog,' or 'turbary,' are applied to tracts where peat is dug. The name 'turf' is generally given to peat in Ireland, although applied in England to grass sods. In certain turf-moors the upper layer is preserved and put on the floor of the pit after the peat is removed to encourage the growth of heather.

The growth in some bogs has been estimated to be at the rate of from 3 to 4 feet in fifty years; in others at

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* 'Report of British Association for 1907' (1908), p. 516.

† W. M. Davis in H. R. Mill's 'International Geography.'

5 or 6 inches in a year; while in some no increase has taken place.* The upper portion is light brown and spongy; lower down the peat as a rule is darker, the basal portions being black; and there may be found bog-oak, blackened by the natural ink formed by the action of iron salts on tannin, as noted by Professor G. S. Boulger (1902).

In England some of the chief areas of Lowland Peat are in Somerset (Sedgemoor), Cambridgeshire (Burwell Fen, etc.), Lincolnshire (Billinghay), Yorkshire and Cumberland (Solway Moss).

In Scotland there are extensive tracts of peat in the lower as well as higher parts of the southern upland regions, and in many other parts, notably in Caithness, the Hebrides, etc.

Owing to the systems of drainage some peaty areas have become shrunken, but the lands have been modified in many places by clay dressings.

In the Fenland the 'buttery clay,' a modification of the marine silt, dug from below peat, has been applied as a heavy dressing on the loose soils of peaty earth, that have been described as like 'rappee snuff,' and are liable to be wind-drifted. In the course of twelve years after this application a dark loamy soil of good fertility has resulted.† (See p. 131.)

Mr. C. E. Moss has noted the growth on some of the well-drained peat-moors of Somerset, of the alder, birch, larch, oak, Scotch fir, and spruce.

Hill or Mountain Peat, largely due to the decay of heather, bog-moss, and grasses, is sometimes called Heather Peat; the necessary moisture is supplied by rains and mists. The peat occurs on slopes in hollows, sometimes on sites of old lakes, and generally in irregular areas, some of which are said to be diminishing by natural causes, material being carried away by wind.

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* See T. R. Jones, *Proc. Geol. Assoc.*, 1880, vi., p. 207; T. Johnson, *Econ. Proc. Roy. Dublin Soc.*, 1899, i., p. 1.

† P. Pusey, *Journ. Roy. Agric. Soc.*, 1840, i., p. 5.

Peat-mosses occur on the uplands of Dartmoor and Bodmin Moor, in many parts of Wales, on the Pennine Hills,* and other moorlands in the North of England, and more extensively in Scotland.

The term 'climbing bogs' has been applied to some peaty areas on upland swamps.

In certain areas peat-bogs, or quagmires, scarred as they are by watery channels, are unsafe for sheep, as on Hindhope in Northumberland.

In Scotland the term 'peat-hag' is applied to upland peaty tracts that have been cut into soft and treacherous boggy channels by shrinkage and stream-erosion.

Quaking or shaking bogs are due to the pressure of water underlying peat and buoying it up. The ground is said to be quaggy, hence the term 'quagmire.'

It is reckoned that peat covers about one-seventh of the area of Ireland, much of it in Mayo, Galway, and Donegal.

The Bog of Allen, an extensive but indefinite tract, is estimated to occupy about 370 acres on the low-lying Carboniferous Limestone. The Lowland Peat is known as Red Bog, and the Mountain Peat as Black Bog.

Petroleum occurs in the peat of Ince Moss in Lancashire, and at Lough Neagh, Antrim; and bog-butter, a hydrocarbon, occurs in peaty areas.

The bursting of bogs, and bog-slides that cause much destruction, are due, in the first instance, to heavy rains on a large tract of peat. Usually the accumulation is based on clay, and the lower and darker portions of the peat are apt to be waterlogged, while the upper and brown portions may be comparatively dry. Where the upper peat has been dug away, the access of much rain-water may cause the lower parts to burst up in the excavations, and a volume of water, charged with peat, may overflow and escape along the outlet below the basin of peat, and flow tumultuously along the stream course.

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* See C. E. Moss, 'Peat-Moors of the Pennines,' *Geograph. Journ.*, 1904, xxiii., p. 660.

Cases have occurred in Ireland where many acres of land have been thus inundated by peaty matter. In December, 1896, after a heavy rainfall, a considerable bog-slide occurred at Knocknageeha, north-east of Killarney, in Co. Kerry. There, for about three miles, the ground slopes from the bog at about 100 feet per mile, the bog itself being as much as 776 feet above sea-level. The bog burst at its lower edge, and gave rise to a black peaty flood, which coursed down the Ownacree, or Quagmire River, carrying great masses of the surface peat, and devastating a large tract of land.*

A bog-slide occurred in 1819, at Owenmore, Erris, Co. Mayo; and in the Solway area there was a notable bursting of a bog in 1771. The Solway mosses, as observed by Mr. T. V. Holmes, are often dome-shaped, the centre being 15 or 20 feet higher than the circumference.

Bog-fires occasionally occur. One took place in July, 1911, at Cappamore, Co. Limerick.

The difficulty that was experienced during the construction of the Liverpool and Manchester Railway (opened 1830) in getting a foundation across Chat Moss, where the peat is from 4 to 30 feet or more in depth, is well known. This tract, like that of Carrington, has been taken up by the Manchester Corporation for conversion into agricultural land by means of the organic and other refuse of the city. Carrington Moss, extending over an area of 1,100 acres, was purchased by the Manchester Corporation in 1886, and has been since used as a dumping-ground for the city refuse. The moss-peat is about 12 feet in depth, and from 45 to 50 tons of refuse per acre have been annually put on the land. As described by Dr. G. V. Poore, 'The muck is dry, and is spread on the surface of the land and ploughed in.' The material consists of street sweepings, night-soil, cinders, and garbage. The area has been drained by means of deep trenches, and, when visited by Dr. Poore in 1897, he found that over the cultivated tracts 'all indications of bog had completely vanished,' and excellent crops of wheat, oats, hay, carrots, and potatoes had been yielded. Much land has since been taken up by nurserymen and market gardeners. The land had to some extent subsided owing to the pressure of the additions made to the soil, and to the moisture taken up by the crops.*

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* G. A. J. Cole, *Nature*, January 14, 1897, p. 254.

Bog-iron-ores, known as meadow or lake ore, and consisting of impure limonite or hydrated peroxide of iron (about 60 per cent.), with sand, clay, manganese-oxide, and organic matter, occur in various parts of Britain in swampy tracts, as in Donegal, Mayo, Queen's County, and Wicklow, and in similar situations in England, Wales, and Scotland. Springs holding iron carbonate in solution precipitate the limonite, usually in stagnant pools, when the water has been exposed to the oxidizing action of the atmosphere; and in some cases it has been held to be due in part to the action of organisms, such as *Gallionella ferruginea*. It has, however, been stated that this diatom 'can live and grow well without any iron at all.' †

Bog-iron-ore often forms an indurated layer below the soil, known as Heath or Bog Pan, Hard Pan, and Iron Pan. Thus hard ferruginous sandstone or conglomerate is formed at the base of soils or subsoils of sand and gravel where they rest on clay. On some of the more elevated and barren moorlands of East Yorkshire, as noted by Mr. C. Fox Strangways, where the subsoil of sand has been formed into a 'pan,' this has to be broken up before the ground can be brought into cultivation.

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* Poore, 'The Earth in Relation to the Preservation and Destruction of Contagia,' 1902, p. 116.

† W. F. Macfadyen, *Nature*, May 21, 1908, p. 55.

A somewhat similar ferruginous crust, known as 'Alios,' is formed underneath the sands in the Landes, near Bordeaux. (See p. 151.)

Another form, known on the peat-moors of the Pennine Hills as the Moor Band or Moor Pan, is described as an impervious layer initiated by the growth of algæ, lichens, liverworts, and mosses.*

Other forms of so-called Hard Pan have been described. Thus in Kansas the term is applied to an intractable soil of stiff, pasty, dark brown clay, with pebbles and small boulders (Glacial till), that requires draining. Again, there is a modified Hard Pan of clayey nature in Kansas, known as Gumbo, more or less local, and a decomposition product transported by streams.† (See p. 42.)

Shell-marl, formed by accumulations of land and freshwater mollusca in swampy tracts, is often associated with peat. It occurs in the Kennet Valley, in the Fenland, at Apethorpe, south-east of King's Cliffe, and other places.

Shell-marl was dug in some of the old freshwater lochs of Caithness, which were drained to allow of the extraction of the marl for agricultural purposes. (See also p. 133.)

In Ireland there are deposits of *Chara-marl*, due to the decay of the calcareous stems of the plant.

Tufa occurs in places in alluvial flats, as in the Chalk area of Hampshire, along the Itchen Valley at Shawford and Twyford, south of Winchester, also near Newbury. A mass of the rock occurs at Southstone, near Shelsley

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* C. E. Moss, *Geograph. Journ.*, May, 1904.

† E. H. S. Bailey, Water-Supply Paper No. 273, *U.S. Geol. Survey*, 1911.

Walsh, Worcestershire, whence were probably obtained the blocks of tufa in the walls of Quatford and Alveley Churches. Considerable accumulations of tufa have been deposited by springs at Matlock, Knaresborough, Dursley in Gloucestershire, and elsewhere.

Diatomite (Kieselguhr), is used for polishing, as tripoli or tripolite, as a fire-proof material, also in the preparation of dynamite and ultramarine. It has been worked in lacustrine tracts at Dinnet, west of Aboyne, in Aberdeenshire, north of Portree in Skye, and at Toome, Co. Antrim.

Diatomaceous earth is made up largely of the siliceous frustules of Diatomaceæ, containing sometimes 80 per cent. of silica. It is known also as Mountain-meal and Bergmehl.

Other economic deposits are obtained from alluvial areas. Recent river-deposits are used for different purposes according to their characters; thus fine sharp sand, adapted for mortar, is obtained from the Trent, and known as Trent Sand; gravel from the Thames, known as 'ballast,' on account of its former extensive use as ballast in vessels, is employed in the manufacture of concrete.

Trent warp, obtained between Littleborough to the south of Gainsborough and East Stockwith to the north, is dug for polishing purposes, as the writer is informed by Mr. F. M. Burton.

The silt from the River Parret, carried by tidal waters from the Severn Sea, is utilized at Bridgwater for the manufacture of Bath bricks for scouring purposes. These bricks were named after the original manufacturer, a Mr. Bath. The 'slime' is allowed to subside at high tide in batches, and a thickness of 12 feet may be formed in one year.

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* T. C. Cantrill, 'Geology of Wyre Forest Coalfield,' 1895, p. 32.

Alluvial areas are not commended as residential sites; there is generally a liability to dampness and in many cases to floods. Occasionally a town, like Hungerford, stretches across an alluvial flat; and some large cities have encroached on to alluvium, though usually after the ground has been artificially raised. (See p. 90.)

Blown Sands.

Blown Sands (Æolian deposits) are met with along the sea-coasts, in inland sandy districts, and in arid or desert regions. The material is mostly composed of more or less worn quartz grains.

Wind-drifted sands occur along many portions of the sea-coast, where broad tracts of sand are exposed at low tide; and the sands become heaped up into hills or dunes of irregular and mountainous outlines, to heights of 150 feet or more. Indeed, they extend over bordering hilly land in Cornwall to 225 feet, and over high ground at Candleston Castle, Merthyrmawr Warren, near the mouth of the Ogmore in Glamorganshire. Elsewhere they form undulating sandy and grassy tracts known as 'links' in Fifeshire, and the ground is utilized for many famous golf courses.

In some areas considerable invasions of wind-drifted sand have occurred, so as to overwhelm good agricultural land and occasionally villages. A sand-flood took place between Nairn and Findhorn about 1695, over a tract known as the Culbin Sands; St. Piran's Church, the site of which is in the sands near Ligger, or Perran Bay (Perranzabuloe, or Perran-in-Sabulo), was buried for several centuries, and re-appeared about 1835; again at Kenfig Burrows, east of Swansea Bay, the old town of Kenfig was invaded by sand-dunes during the fifteenth and sixteenth centuries.

Sand is blown inland from sandy cliffs, as on the Norfolk coast near Cromer; it is likewise drifted from sandy soils and subsoils, including tracts of sandy gravel, as in West Norfolk and Suffolk, and in East Lincolnshire, forming warrens on areas respectively of Chalk and Lias.

The more important tracts of Blown Sand are those which fringe the coasts at intervals all round the British Isles, the mere enumeration of which would occupy much space.

Off the Lancashire coast the Blown Sand hills are known as 'meols' and 'rabbit-warrens'; in many parts of Wales and in North Devon they are known as 'burrows'; and in North Cornwall as 'towans.' The Shirdley Hill Sand, near Ormskirk, and other places in Lancashire, is partly marine, but mainly Blown Sand of ancient date.

In Norfolk there are the Marram Hills or meals, between Hunstanton and Blakeney; farther south are the Denes of Yarmouth and Lowestoft, where Blown Sand, Beach Sand, and Shingle are much intermixed.

The Ardeer Sands of Irvine Bay in Ayrshire are utilized as the site of Nobel's Explosive Factory; and there is a similar factory between Gwithian and Phillack Towans, on the borders of St. Ives Bay, in Cornwall.

In describing the Blown Sands of the north coast of Cornwall, Mr. C. Reid has observed that the dunes or towans are by no means barren; if movement ceases, they soon become covered with vegetation, with the marram-grass on the drier parts, and the creeping sedge on the flatter and wetter dunes. In a few years such tracts may be covered by turf, largely consisting of wild thyme. Moreover, basin-shaped hollows are scoured out by the wind till the old soil, 30 or 40 feet below, is laid bare, 'and in these hollows there is either a gently inclined stony waste, or a patch of marsh, sometimes with bulrushes.'*

* 'Geology of Newquay,' *Mem. Geol. Survey*, 1906, p. 68.

Grasses with long roots and other plants have been utilized to bind the loose sand and hinder the drifting over cultivated lands; they include the following:

Marram or Marrum grass, or sea-bent (*Ammophila arundinacea*).
Lime-grass (*Elymus arenarius*).
Sand-sedge (*Carex arenaria*).
Sea-couch grass (*Agropyron junceum*).

The gorse, tamarisk, wild thyme, heather, sea-buckthorn, maritime pines, privet, honeysuckle, and elder are said to grow well on sand-dunes.

The shelly sands of the Cornish coast contain sometimes as much as 70 per cent. of shell-fragments (carbonate of lime), and the material has long been used as a fertilizer. Material was obtained not only from Blown Sand hills, but from the foreshore at Bude, Padstow, Falmouth Harbour, and many other places, and much of it was naturally impregnated with sea-salt.

At St. Ives Bay the sands contain many mineral ingredients derived from mining refuse carried down by the Red River; moreover, material from the estuarine and alluvial tracts at low-tide is liable to be wind-drifted; and, as noted by Mr. C. Reid, the soils are modified by this drifted mineral dust and sand near Hayle and Lelant.*

In the Island of Colonsay shell-sand, distributed by the wind, has helped to fertilize the hill-pastures, and the same has been the case in many other tracts, as in Ayrshire, where the inland soils have been improved.

In certain cases the hills of Blown Sand serve to protect low-lying agricultural land that borders the coast; nevertheless, too much Blown Sand occurs in some tracts, so as to prove injurious to adjacent land under cultivation.

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* See also T. Crook and G. M. Davies, *Geol. Mag.*, 1909, p. 120.

In Donegal material from the calcareous sand-dunes of Lough Swilly is used as manure.

Blown Sea-sand, although liable to be more or less saline, has sometimes been utilized for mortar and brick-making. The sand of the Warren, near Exmouth, has been used in foundries for moulding purposes.

Clay Dunes have been formed of clayey particles derived from the mud of lagoons that has cracked and curled up in dry seasons. Thus Mr. G. N. Coffey has described ridges so formed of wind-drifted clay in South Texas, near the mouth of the Rio Grande. The ridges are several miles long, 30 feet high, and 200 or 300 yards in width.*

Recent Marine Deposits.

Shelly sands with marine mollusca, known as Burtle Beds, occur in the Somerset Levels, south of the Mendip Hills, at Burtle near Glastonbury, Chedzoy, and Westonzoyland. (See p. 76.)

Other shell-sands, of more modern date, occur at the east end of Sheppey, where the material has been used for making paths, etc., and there is a shell beach at Barracane, in Woolacombe Bay, North Devon.

The Formby and Leasowe Beds, described by T. Mellard Reade, consist mainly of marine silt, and occur near Formby and Hightown, between Liverpool and Southport.

Among the more extensive tracts of recent shingle are the pebble or popple beach north of Westward Ho! fringing Northam Burrows, west of Appledore; and the Chesil Bank, which extends from Portland to near Burton Bradstock, and thence to West Bay, Bridport. The finer material at Bridport has been utilized for cleaning vats, etc.

Dungeness, in Kent, which rises up to 20 feet above

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* *Journ. Geol.* (Chicago), 1909, xvii., p. 754.

Ordnance datum, is the most extensive area of shingle, formed mainly of flint, with chert, quartz, quartzite, fine and coarse pebbles, and subangular stones. It is actually cultivated in places by Boulderwall, south-east of Lydd, but is mostly a bare tract, where wooden boards strapped to the boots of the pedestrian are necessary if comfortable progress is desired. Orford Beach, which extends from the mouth of the Ore to near Aldeburgh, and Weybourn Beach in Norfolk, are among many other noteworthy beaches.

In Lancashire the Preesall Shingle, of Preesall Hill, east of Fleetwood, is an old beach with marine shells, and has been worked for gravel. The Murrough, which extends from Wicklow to near Greystones, is a bank of shingle.

So-called 'musical sands' have been met with on many beaches in different parts of the British Isles and abroad, and in some inland localities. They give rise to sonorous, swishing, or squeaking sounds when trodden upon. According to Mr. C. Carus-Wilson, the musical notes are produced by smooth and clean grains of quartz fairly uniform in shape and size, that have been sorted naturally by the action of winds and waves.* When irregular in shape, the particles give rise to squeaking or other non-musical sounds. Mr. H. C. Bolton has observed that certain patches of sand are musical when dry and squeak when moist.†

Quicksands, bordering a sea-coast or estuary, are sands that become so water-logged with the incoming tide as to lose their stability and become dangerous; such occur along the mouth of the Solway, the Pilling Sands near Fleetwood, and on the foreshore west of Portmadoc.

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* *Nature*, August 6, 1891, and August 5, 1909; *Morning Post*, January 26, 1912.

† *Nature*, November 13, 1890.

Elsewhere, as on the Maplin Sands, on the Essex coast, vehicles can be driven at low-tide along the sandy foreshore from the mainland to Foulness Island; and in Beaumaris Bay, in old times, the coach-route to Ireland is stated to have been taken for three miles along the Lavan Sands to Beaumaris Ferry.*

COAST EROSION.

It is a remarkable fact that, despite the waste of the sea-coast, the actual area of England and Wales, according to the Director-General of the Ordnance Survey, is greater than it was, owing to the reclamation of land.

In the Reports of the Royal Commission on Coast Erosion descriptions are given of the reclamation of alluvial flats and salt-marshes, and of the aid given by various plants in the accretion of mud-flats, and in the checking of wind-drifted material. (See p. 201.)

The tidal mud naturally contains a good deal of sodium chloride; but in time certain areas when raised to the level of high-water spring-tides, as on the borders of the Wash, get covered with vegetation, and become suitable for grazing. Among the plants there found are the glasswort, locally known as samphire (*Salicornia herbacea*), and the sea-grass (*Zostera marina*). In Southampton Water rice-grass (*Spartina townsendi*), first noticed in 1870, has been important in the aid it has given in the accumulation of mud.† By means of embankments many such areas have been reclaimed, forming rich grazing-grounds. When drained the areas naturally shrink; but by processes of warping, as along the Humber coast, the ground is gradually raised.

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* J. E. Lloyd, 'Carnarvonshire' (Cambridge County Geographies), 1911, p. 44.

† See 'Report of Royal Commission on Coast Erosion,' 1909, vol. ii., part ii., p. 143, etc.; 1911, vol. iii., p. 17; also A. G. Tansley, 1911, p. 330; and S. B. J. Skertchly, 'Geology of Fenland,' *Mem. Geol. Survey*, 1877, p. 9.

Excellent land has been obtained at various periods, from the time of the Roman occupation, by embankments along the borders of the Wash, Pagham Harbour, and elsewhere, and by the draining of meres, marshes, and swamps, as in the Fenland, Romney Marsh, etc.

Notable has been the gradual growth and embankment of Sunk Island, in the Humber, which, in 1668, had about seven acres of enclosed land, and now has 8,430 acres of excellent arable land, with many farms, the area being attached to the mainland near Patrington.*

The greater losses of land have been along the Holderness coast of Yorkshire, in Norfolk, Suffolk, and Sheppey.

The general results are that while 'on the one hand, considerable areas of agricultural land are lost, sea-coast towns are injured, and harbours tend to silt up; on the other, large areas of valuable agricultural land are gained, and these areas on the average are more valuable than those which are lost.' The gain has been almost entirely in tidal estuaries, the loss on the open coast. In most cases the provision to protect agricultural land, bordered by sea-cliffs that are formed of easily eroded strata, 'would involve a cost far in excess of the value of the land.'

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* Report (*op. cit.*), Appendices, p. 4 (map).

CHAPTER XVIII

GEOLOGICAL FORMATIONS (*Continued*).

I. QUATERNARY (RECENT AND PLEISTOCENE)

River-gravel and Brickearth, Estuarine Beds, and Raised Beaches.

The older deposits of river-valleys, that often extend over considerable areas, form a terrace or a series of terraces or platforms above the alluvial flats, and they are for the most part free from liability to floods. They pass into estuarine beds and raised beaches along the coast.

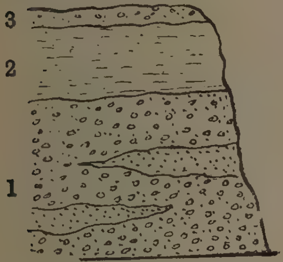
In the United States the term 'bench-lands' is applied to terraces in the valleys that abut against the bluff line of the foot hills.

The nature of these deposits varies in different river-valleys, and even in the same river-valley. Thus in the case of the Thames the gravels below Oxford are practically devoid of calcareous stones, and form a dry hungry soil in some cases; whereas above Oxford the gravel contains many flat limestone pebbles, as may be observed near Standlake and higher up the river-course, and its tributaries in Wiltshire and Gloucestershire. There the soil is fertile, and not unlike that of Cornbrash, where the limestone pebbles form a kind of brash. Along the Great Ouse Valley in Bedfordshire, the Nene in Northamptonshire, and the Ouse in Wiltshire (near Melksham), there is much limestone-gravel.

The soil on this gravel, a fertile brown loamy and sandy earth, is in part a residue due to dissolution of limestone fragments, the underlying gravel being decalcified and 'piped.' Where protected by a clayey covering, the limestone pebbles are naturally preserved, as in the pit shown in Fig. 15 along the Brue Valley in Somerset.

These limestone gravels are sometimes cemented by calcareous matter into a conglomerate, as at Church Handborough in Oxfordshire and other localities.

There is much valley-gravel bordering the Thames, as at Long Wittenham, Wallingford, and Maidenhead in Berkshire, at Dorchester in Oxfordshire, and Great Marlow in Buckinghamshire. From Slough eastwards to Ilford and Upminster there are large areas of loam or brickearth that have been extensively dug for brick-making, where not under cultivation. Fruit and market gardening, as elsewhere noted (see p. 149), is largely carried on in the gravelly, sandy, and loamy areas of the older river deposits.



3, Fine gravelly and loamy soil, 6 inches.

2, Reddish-brown clayey loam, 2 feet.

1, Gravel composed of smooth, flat pebbles of limestone, subangular flints, etc., with seams of sand, seen to depth of 4 feet 6 inches.

FIG. 15.—GRAVEL-PIT BETWEEN WRAXHILL FARM AND ALHAMPTON, NEAR CASTLE CARY, SOMERSET.

The gravel tracts before mentioned, and those of Staines, Chertsey, Molesey, Twickenham, and Kew, are largely built over; but some of the lower terrace-gravel-lands near the Thames are liable to be damp from the rising of ground-water, which is more or less connected with that of the river.

In London itself, in old times, along the borders of the Kingsland Road, much land was lowered—from 4 to 10 feet—by the excavation of brickearth, and afterwards levelled, ploughed, and laid down to grass.* Many of the old villages now incorporated in London were built on valley gravel, from which supplies of water were for many years obtained.

The valley deposits of the Trent afford good soils of gravelly loam; and in the vale of York there is considerable variety of superficial deposits: gravels and sands, loams and clays, some alluvial, some Glacial in origin, and these give rise in general to fertile soils.

The estuarine beds of the Clyde (Clyde Valley Beds) consist of silt, sand and clay, often shelly, and they occur at elevations of 25 to 30 feet, sloping gently seawards.

Bordering the Forth in the neighbourhood of Falkirk and Stirling are low-lying tracts with a deep fertile loam, well cultivated, and yielding crops of potatoes, corn, turnips, etc.

These tracts, known as 'carse-lands,' include the carse of Falkirk, that of Stirling, and also Gowrie (between Perth and Dundee, bordering the Firth of Tay); and they consist of alluvial gravels and loams in some places, and of raised beach deposits in others.

Raised beaches which yield a light, gravelly, and sandy soil are cultivated for corn, etc., in many parts of Scotland, and in particular for oats on the borders of the north-west Highlands, in Colonsay, etc.

The stream tin deposits of Cornwall, which occurred in the valleys beneath alluvial and estuarine deposits, were made up of gravelly strata with rounded masses of tin-ore; but the ore having been practically worked out, the sites of the old workings, as remarked by Mr. J. B. Hill, 'now remain as tumbled and disordered ground, much of which, from an agricultural standpoint, is a waste.'*

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* J. Middleton, 'Agriculture of Middlesex,' 2nd edit., 1807, p. 23.

Auriferous gravels or placer deposits occur in the Strath of Kildonan, near Helmsdale, in Sutherland; but after trials in 1869, and again in 1911, it has been found that the deposits cannot be profitably worked.

Angular Drift.

Fringing the northern portions of the Cotteswold Hills there are extensive accumulations of Oolitic rubble opened up in places to a depth of 20 or 30 feet, and dug as 'gravel' for mending paths. Some of the more remarkable accumulations occur south of Dursley, south of Harescomb, at Leckhampton Hill, where the rubble is seen to be banked up at angles of 30 to 40 degrees, and west of Syreford, near Andoversford.

Perhaps the most instructive sections are those on Bredon Hill, where the Inferior Oolite is shown to be broken up and irregularly weathered into a fine and coarse gravelly-looking rubble. This rubble at one part of a large stone-quarry was from 25 to 40 feet deep (base not seen), and about 60 yards wide, with isolated masses and pinnacles of unweathered limestone.

W. C. Lucy, in 1869, expressed the view that the material was 'attributable to frozen snow or land-ice, which, when the thaw set in, would slip down, carrying with it the *detritus* of the Freestone.' Witchell, in 1875, showed that in places the rubble was intercalated with the rolled Oolitic gravel of the river-valleys. In his opinion some of this Drift was 'due to storm-waters or surface-drainage, which brought the detritus down the hill upon a frozen surface, and deposited it in those places where the frost usually disappeared in spring before it left the higher ground.'*

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* 'Geology of Falmouth and Truro,' *Geol. Survey*, 1906, p. 95.

The erosion of other limestone areas, especially of the Chalk, in combes where no surface-water is now found, has attracted much attention. S. V. Wood, jun., in 1882, attributed much to the effect of thaw on the upper 2 or 3 feet of frozen ground, and the sliding away of the thawed layers of sludge.

Mr. C. Reid subsequently explained that the dry Chalk valleys were excavated when the ground was permanently frozen and the rains in summer had great erosive power; and that the Coombe Rock which is distributed over considerable tracts of the lowlands in Sussex was the result of this denudation.†

Along the coast from Chichester to Brighton there is a tract of gravels and loams, in part of tumultuous character, that appear to be old alluvial deposits.

The Coombe Rock consists of pale Drift made up of broken and angular flints, and occasional flint pebbles (of Eocene origin), with chalky and sandy matrix. It is sometimes known as the 'white gravel.' It contains also large unworn flints and many chips of flint. The surface is piped, the beds being decalcified, and a 'red gravel' results. Locally there is a good deal of reddish, sandy Drift below the paler, chalky Drift. The flints are used for building walls and for road-metal.

The Coombe Rock passes into a stony loam known as 'Shrave.' Near Portslade, brickearth has been dug above the Coombe Rock or 'Marl,' and beneath that there are red gravel and sand, and other deposits as represented in Fig. 16. The soil is preserved when brickearth is dug in this district, and afterwards spread over the ground for horticultural purposes. The brickearth at Broadwater is 6 to 8 feet thick; it is a clean loam, with sandy loam soil, and vine-roots extend 5 or 6 feet down into the subsoil.

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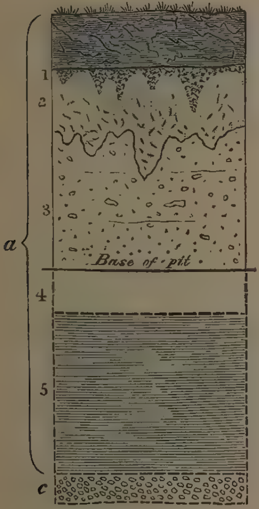
* See H. B. Woodward, 'Jurassic Rocks of Britain,' iv., p. 462; *Mem. Geol. Survey*, 1894.

† *Quart. Journ. Geol. Soc.*, 1887, xliii., p. 364.

Dry Valley Gravel, as it is sometimes called, occurs in the higher parts of many Chalk valleys, and in some cases may be a decalcified form of the Coombe Rock. It occurs in many localities on the Wiltshire Downs, and above the ordinary outlets of springs and streams in the deep valleys trenched along the dip-slope of the Chiltern Hills, and elsewhere.



		Feet.	
a	Light-brown brickearth with few flints	4	Coombe Rock.
	1, Angular flint and chalk rubble	1 to 3	
	2, Chalk and flint rubble with ochreous sand and flints at base ...	4 to 6	
	3, Unstratified chalk and flint rubble with large unworn flints ...	8 to 10	
	4, White clay	2	
	5, Brown clay	12	
c,	Shingle and large flints with *Pecten* and *Cardium* (raised beach) ...	3	
	Chalk (below).		

FIG. 16.—SECTION OF BRICKEARTH AND GRAVEL-PIT AT PORTSLADE, SUSSEX. (Prestwich.*)

Particulars of the beds 4 and 5 were obtained by Prestwich in 1879 from the foreman of the pit.

In the valley north of Hughenden (Hitchendon), High

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* *Quart. Journ. Geol. Soc.*, 1892, xlviii., p. 270.

Wycombe, there is a deposit from 4 to 12 feet thick of dark clayey loam, with unworn and broken fragments of flint, sometimes approaching a gravel in appearance. This was evidently due, in the main, to a downwash of Clay-with-flints and brickearth from the hills. The flinty loam occurs part of the way up the slopes with bare Chalk above. (See Fig. 17.) Near Croydon there is in the lower grounds of dry valleys from 3 to 6 feet of flinty and clayey loam, somewhat sticky in nature, and apt to cake, near the outcrops of Eocene clays and sands.

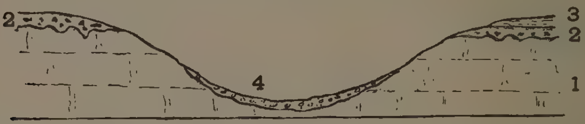

FIG. 17.—SECTION ACROSS VALLEY NORTH OF HUGHENDEN, NEAR HIGH WYCOMBE.

4, Dark clayey loam with unworn and broken flints, in part gravelly in appearance, derived as downwash from the Clay-with-flints and brickearth.
3, Brickearth.
2, Clay-with-flints.
1, Chalk-with-flints.

Scarp Drift.—Extensive accumulations of flinty and chalky loam are distributed over the surfaces of the land, below some of the great Chalk escarpments. Mr. F. J. Bennett has described as 'Scarp Drift' the fine buff chalky loam, with lenticular beds of flints, which occurs along the foot and lower slopes of the North Downs. At Lower Halling, on the Medway borders, the accumulation was 40 feet thick.*

This appears to be somewhat similar to deposits described as Rainwash, Landwash, Run-of-the-hill, Rubble Drift, and Angular Detritus, by Prestwich and others. Thus there is Chalk rubble with broken flints and loam,

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* *Proc. Geol. Assoc.*, 1904, xviii., p. 465.

35 feet and more thick, near Chilton, south-west of Didcot; and near Princes Risborough there is much similar chalky and flinty Drift, approaching Coombe Rock in character.

In the Vale of Pewsey, over a tract mainly of Gault Clay, and partly of Upper Greensand and Kimeridge Clay, between Urchfont and Etchilhampton, and at intervals from Stert to near Bratton, there is an accumulation of fine Chalk rubble and flint gravel, with some débris of Upper Greensand, 3 to 10 feet thick. The deposit is covered in places with stiff brown or grey clay, which forms a marly soil, the joints and cracks in the clay being coated with calcareous matter.

It is possible that in some places such accumulations were due to the former marling of the land, as in old times 160 cart-loads per acre of Chalk were sometimes put on the clayey and sandy lands of Wiltshire.*

The Chalk rubble was seen on the Kimeridge Clay near East Coulston; and, farther west, Mr. F. J. Bennett observed its occurrence on the low grounds opposite the valleys at Tinhead and Bratton, whence in his opinion it had been derived.†

In the Holderness district there are tracts of Chalk rubble, due to the subaerial wash of the land, and described as 'Chalk wash' by J. R. Dakyns.

Soil Movements.

Soil movements, or creep of soil and subsoil, occur on slopes and along valleys in most regions;‡ in fact, it has been stated that the soil is never at rest, although it may be observed that loose, pervious earth will withstand a good deal of rain without being greatly disturbed. The mud-streams along the Cromer coast, where the Drift Clay is carried down the cliffs and spread in thin layers over the beach, and the movements in clay cuttings of railways, are examples of surface movements of soil and substrata.

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* T. Davis, 'Agriculture of Wiltshire,' 1794, p. 63.

† 'Summary of Progress,' *Géol. Survey for* 1898 (1899), p. 188; and Jukes Browne, 'Geology of Devizes,' *Mem. Geol. Survey*, 1905, p. 43.

‡ C. Davison, *Geol. Mag.*, 1889, p. 255.

In such mechanical movements the actions of frost and thaw and the melting of snow are potent in causing the descent of earth and stones, notably in the case of avalanches. To such causes have been attributed the disturbed surface strata, which have been squeezed or nipped up and crumpled, producing what have been termed 'festoons,' and by Mr. F. J. C. Spurrell* 'underplight.' These features are often conspicuous where the surface strata are composed of gravel, sand, clay, loam, and chalky rubble. Peaty tracts on slopes, as the writer has noticed on Raasay, become much fissured by soil movements.

The term *Dead-lime*† is applied in Norfolk and Suffolk to disintegrated and more or less decomposed lumpy or rubbly Chalk, that is mixed with sand and gravel, if there be a capping of such deposits. Flints and broken flints occur irregularly in it, and sometimes with the longer axes vertical. This deposit is probably due in certain cases to soil movements, but is not always to be distinguished from the glaciated surface of Chalk where influenced by the land-ice which brought the chalky Boulder Clay.

Similar disturbed surfaces of Chalk are well seen at Grays, in Essex.

Gravelly and sandy débris is often found filling irregular troughs and furrows in clays, and some deposits of this

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* 'A Sketch of the History of the Rivers and Denudation of West Kent,' 1886.

† S. B. J. Skertchly, 'Manufacture of Gun-flints,' *Mem. Geol. Survey*, 1879, p. 6; H. B. Woodward, 'Geology of Norwich,' 1881, pp. 134, 137.

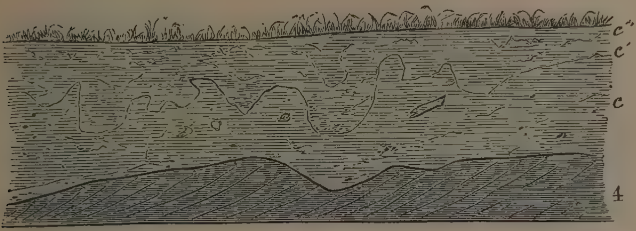

FIG. 18.—SECTION AT BRICKEARTH PIT, LIMPSFIELD COMMON, SURREY. (Prestwich.*)

		Feet.
c'',	Bleached loamy soil	1
c',	Disturbed brickearth with angular débris	8 to 10
c,	Undisturbed brickearth with angular débris	
4,	Lower Greensand (soft loamy grit).	

The angular débris consists of chert, ragstone, and ironstone derived from the Lower Greensand of the neighbourhood, and there are also Tertiary flint pebbles and angular and subangular flints. The disturbed beds may have been caused by some form of ice-action, according to Prestwich.

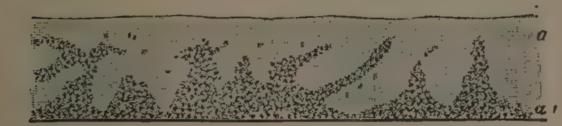

FIG. 19.—SECTION IN THE CLIFF NEAR PAGHAM, SUSSEX. (Prestwich.†)

a,	Brickearth.	about 5 feet.
a',	Irregular seams of flint-gravel.	

Evidence is here shown of disturbance, perhaps due to soil movements.

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* *Quart. Journ. Geol. Soc.*, 1891, xlvii., p. 146.
† *Ibid.*, 1892, vol. xlviii., p. 271.

nature were described as 'Warp Drift' by Trimmer, and as 'Trail' by the Rev. O. Fisher, who pointed out that the pebbles often occurred with their longer axes vertical.

Where valley gravels rest on clays, as at Bath and elsewhere, channels are not uncommonly found in the clay filled with gravel from the overlying deposits. The erosion here may be attributed to the effect of underground streams, and it may lead to superficial soil and subsoil movements.

Instances occur where a trough in flint-gravel is filled with clay, when there is no evidence of decalcification of the gravel to account for the features. Such a case was observed at Alderbury, near Salisbury, and it appeared to be due to the irregular intersection in the gravel-pit of a disturbed band of clay. Some illustrations of superficially disturbed strata are given in Figs. 18 and 19, and on Plate IV.

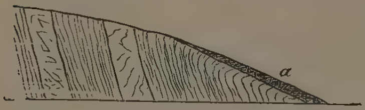

FIG. 20.—ROAD-CUTTING NEAR THE TOP OF KITSON HILL, NEAR ILFRACOMBE. (Prestwich.*)

a, Rubble Drift, 3 feet, resting on Devonian rocks with quartz veins.

The section was seen at about 400 feet above sea-level, and showed the reversed edges or terminal curvature of the slaty rocks beneath a covering of Rubble Drift or Talus.

The 'terminal curvature' of slaty beds, noticeable in many parts of Devon, has been ascribed to the effects of frost under severer climatic conditions; but, like other phenomena, the disturbances may locally be produced or modified by various agencies: soil-slipping (as in Fig. 20), roots of trees, the effects of denudation on contorted slates, and in glaciated regions to the movements of land-ice.

The so-called 'stone rivers' of the Falkland Isles have been attributed to soil-cap: movements. These broad tracts of gently-sloping ground, that is striped or chan-

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* *Quart. Journ. Geol. Soc.*, 1892, xlviii., p. 318.

PLATE IV.

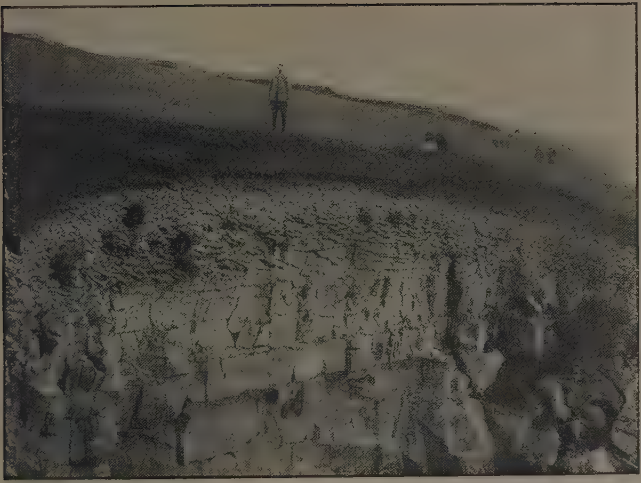

Photo by Prof. S. H. Reynolds.

(i.) WEATHERED PORTLAND STONE, EAST OF ST. ALBAN'S HEAD, DORSET.

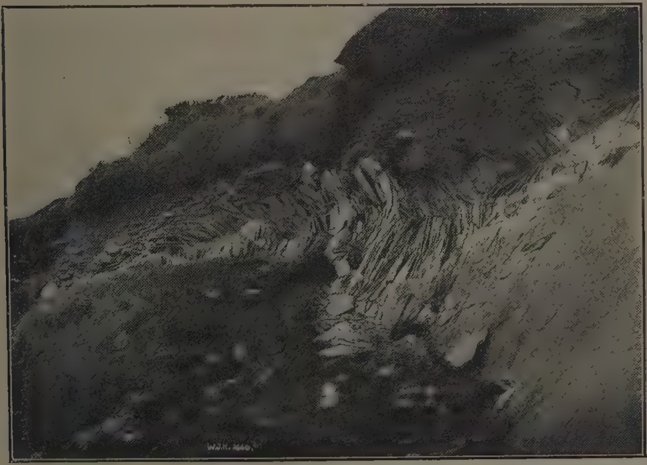

Photo by W. J. Harrison.

(ii.) SURFACE-CREEP IN CAMBRIAN SLATES, NEAR ST. DAVID'S, PEMBROKESHIRE.

nelled in the direction of the slope, are strewn with angular blocks of quartzite, from 2 to 20 feet long. Beneath the ground there is a flow of water. The movements have been explained as due to alternations of frost and thaw, the finer material being carried away by streamlets. This view is to a certain extent supported by Dr. C. Davison,* who remarks that the strata from which the blocks have been derived consist of bands of hard quartzite, separated by seams of soft and crumbling sandstone. The softer materials would be readily removed by streams, but the hard and heavy blocks would remain, because they could not be transported.

The explanation might be applied to the scattered greywethers on the Wiltshire Downs, of which but a small number remain of those that formerly were to be seen.

Landslips.

Landslips occur on steep slopes inland, and along many parts of the coast. Where porous strata rest on a clayey foundation, and have a slight inclination towards a valley or sea-coast, the action of the rain and underground water that descends to the clay, and is thrown out in springs, tends to produce landslides by weakening the foundation, partly in some cases by the undermining and carrying away of material. Great fissures or clefts are also formed near the margin of cliffs, and in the course of time huge masses of strata break away in the form of landslips. Thus clay cliffs which have become much contracted and fissured are also liable to founder.

Earthquakes, which are intimately connected with faulting or rupture of rocks beneath the surface, have been known to promote landslips, when the conditions of the rock-formations at the surface are unstable. In the same way mining operations, with underground tunnels, have caused subsidences that have led to disastrous landslides.

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* *Geol. Mag.*, 1889, p. 390.

Landslips are met with along the more prominent escarpments, as on the Cotteswold Hills, in the Stroud Valley, and on the borders of the deep valleys near Bath, where Great Oolite rests on Fuller's Earth Clay, or Inferior Oolite and Sands on Lias Clay. Others occur from time to time in the Lias and Oolitic strata of the moorlands of East Yorkshire.

On the Blackdown Hills of Somerset and Devon the Upper Greensand has slipped much on the steep slopes above the Lias and Red Marls. Again, on the coast of the Isle of Wight at Ventnor, where Upper Greensand rests on Gault (known as 'the blue slipper'), and along the coast between Lyme Regis and Axmouth, where Chalk and Upper Greensand rest on Lias, Rhætic, and Red Marls, great and picturesque landslips have resulted.

In the neighbourhood of Dover, as at St. Margaret's, immense masses of Chalk occasionally break away from the cliffs. The London Clay of Sheppey and of the Essex coast, capped by sandy and gravelly deposits, is subject to great slips, caused by the expansion and contraction of the clay in wet and dry seasons, and landslips are specially liable to occur when heavy rains fall after prolonged drought. Among the contorted Drifts of the Cromer coast in Norfolk many great slips, as well as mud-streams, are similarly caused.

Local slips of small extent may lead to a misinterpretation of the geology. Thus the attention of Mr. E. T. Newton and the writer was called to the occurrence of remains of hippopotamus in the London Clay (!) near Wembley Park, in the higher part of the Brent Valley. The fossil remains, however, proved, as might have been anticipated, to come from a local gravelly Drift deposit, which was opened up beneath a mass of reconstructed, or slipped, London Clay.

Near Axminster, on the branch railway to Lyme Regis, the cuttings showed slipped masses of Red Marls over valley gravel.

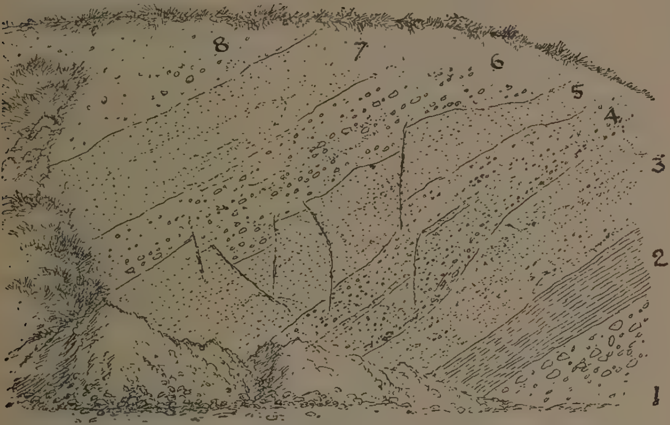

FIG. 21.—SECTION IN BOVEY BEDS, BY WOLBOROUGH CHURCH, NEWTON ABBOT.* (1896.)

8, Gravel and sand.
7, Reddish sand.
6, Gravel and sand.
5, Reddish sand.
4, Sand and fine gravel.
3, Sand.
2, Clay.
1, Coarse gravel.

Height of section, about 30 feet. Length, 60 yards.

The strata have an inclination towards the south-east of 35 to 45 degrees.

On the margins of valleys, the slopes, when excavated, not infrequently show miniature faulting in the strata. Such features were exhibited in the Bagshot Sands of the northern part of the Brooklands Automobile Racing Ground near Weybridge, and in the mixed deposits of the Bovey Beds near Newton Abbot. (See Fig. 21.)

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* H. B. Woodward, *Proc. Geol. Assoc.*, 1900, xvi., p. 440.

Darwin (1881, p. 278) has described the tiny ledges of earth, sometimes known as 'sheep-walks,' that so often may be seen on steep hillsides in this country and in many parts of the world: 'Their formation has been attributed to animals travelling repeatedly along the slope in the same horizontal lines while grazing, and that they do thus move and use the ledges is certain.' Sheep, indeed, especially utilize the tracks. These are approximately horizontal, like miniature cliffs, but run one into another here and there, and sometimes cross.

Such ledges occur on Chalk slopes and on Boulder Drift, as noted by Darwin. Good examples can be seen on the steep scarps of Portland Beds, in the combes of West Hill, and Renscombe, in the Isle of Purbeck, also on the slopes of Middle Lias beneath the marlstone north-west of Banbury.

Darwin attributed their formation to the washing down of soil and worm-castings, accompanied by slight slipping of the ground, and to the subsequent influence of sheep and oxen, and there is no doubt that this explanation is applicable to most cases in Britain.

Other observers, however, have pointed out that somewhat similar ledges occur on mountain-slopes and hillsides, where the action of earthworms is insignificant, and where no cattle have been known to have grazed. Mr. A. Ernst thus directed attention to the ledges that are very abundant on the mountain-slopes in Venezuela, where they are composed of a sandy loam derived from the decomposition of gneiss. In rainy seasons there is much soil movement, and 'the slope not being uniform in all its parts, nor the disintegration of the rock everywhere of the same depth and degree, it follows that the sliding too will be unequal, and so an extraordinarily complicated system of stresses and counter-stresses is developed, which, of course, causes the surface to take a wrinkled or wavy appearance.'*

All slopes are liable to receive a certain amount of downwash or rainwash in the form of earthy débris or angular detritus, and the accumulation, which is naturally greatest in amount along the foot of the hills or mountains (like the débris in quarries), etc., is known generally as *Talus*. The character of the material varies, of course, according to the nature of the rock-formation. Where hard igneous or sedimentary formations occur, the material is, for the most part, formed of loose and angular rock-fragments of various sizes. To this material the term *Scree* is generally applied. Notable examples occur on the slopes of many mountains, lofty hills, and rocky cliffs, as at Wastwater, in the Pass of Brander by Loch Awe, and in many localities beneath crags of Carboniferous Limestone and Millstone Grit. Locally, these accumulations of fallen fragments, dislodged by frost and other meteoric agencies, are known as Clitters, Clatters, Glitters, and Glidders. The lower portions (or Talus) contain more earthy material, due to attrition, and are often fitted for the growth of trees. (See Plate III.)

On some coasts, as below Gad Cliff, in Dorset, huge blocks occur, derived in this case from the Portland limestones and chert beds; consequently, any attempt to traverse the beach westwards is most arduous, and the pedestrian learns that ignorance is not bliss when he ascertains that progress is finally arrested by the sea washing against the cliffs, and he has to retrace his steps.

Dr. A. W. Rogers has described screes derived from crags of dolerite in the Cape of Good Hope, and made up of angular blocks 2 to 6 feet long. They cover the hill-slopes to such a depth that no bush can grow, 'and occasionally one meets with a block so delicately poised that it moves when touched, though it weighs many hundred pounds. Fatal accidents occasionally happen through careless climbing over this extremely coarse scree, owing to a large block turning over and crushing the unfortunate person.'†

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* *Nature*, February 28, 1889, p. 416; see also A. G. Greenhill, *ibid.*, March 14, 1889, p. 461.

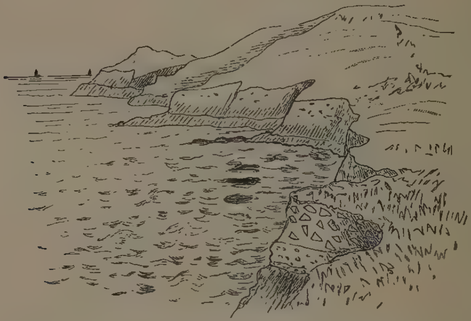

FIG. 22.—COAST TOWARDS ROSEMULLION HEAD, NEAR FALMOUTH. (W. A. E. Ussher.)

Rock-platforms (Portscatho Series, etc.) at sea-level, with raised beach and head above.

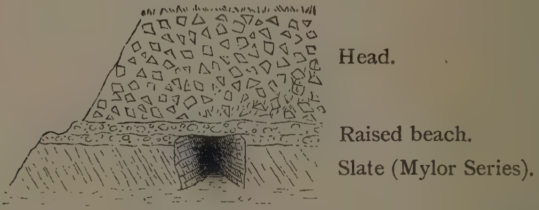

FIG. 23.—CLIFF AT GODREVY, EAST OF ST. IVES BAY, CORNWALL. (W. A. E. Ussher.)*

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* *Geol. Mag.*, 1879, pp. 168, 205.

† 'Fifteenth Annual Report of the Geological Commission, Cape Town,' 1911, p. 46.

The term *Head* has been applied to surface accumulations of angular and sub-angular stones in a sandy or clayey matrix that are to be seen along many coasts, and notably in Cornwall, where the stones comprise quartz, slate, blocks of granite, greenstone, etc. Good examples are seen near Falmouth and in St. Ives Bay (see Figs. 22 and 23), while to the east of Marazion there is a cliff of Head 40 feet high. These deposits, though they may locally be formed to some slight extent now, are for the most part of ancient date, and were accumulated during Pleistocene times under colder climatic conditions.

The rubble of loose weathered rock-fragments (subsoil) that is removed as waste from the surface of a freestone quarry is sometimes termed Quarry-head, Ridding, etc.

Clay-with-Flints.

This term is applied (though not restricted) to an accumulation of unworn flints and red clay that occurs on the surface of Chalk tracts, and lines pipes or cavities, which sometimes extend to a considerable depth. (See p. 64.) As pointed out by Mr. W. Whitaker, it is a residual deposit due to the dissolution of the Chalk, leaving the flints and earthy matter, which attain a thickness of from 1 to about 5 feet.

The pipes extend vertically or obliquely downwards in a more or less circular form, diminishing in size the deeper they occur, and sometimes their extent is indicated in a Chalk-pit by a circular mass or pocket of Clay-with-flints at some depth from the surface, where an oblique pipe has been cut through in the working of the Chalk.

The accumulation shown on the Geological Survey maps as Clay-with-flints, and sometimes as Clay-with-flints and loam, is in reality a very mixed deposit. While in places it gives rise to a stony soil with much clay and heavy loam, sometimes to fields crowded with flints (see p. 83), the soil is elsewhere lighter, less stony, and more sandy or loamy. This is notably the case at Harpenden, and on the Rothamsted experimental farm.

With a foundation of Chalk, which rises in irregular pinnacles to near the surface, coated with an irregular accumulation of Clay-with-flints (proper), the hollows due to dissolution of the Chalk are largely filled with a mixed and varied mass of sands, pebbly beds, and rough gravel, in part relics of Eocene strata, in part Drift. Under such conditions the subsoil is liable to vary in every field to some extent; there would be drier and damper patches, and the soil, crowded with flints in some places, would be stiff clay in others, and light sand or loam elsewhere.

Extensive tracts of Clay-with-flints occur in Hertfordshire, Buckinghamshire, and Oxfordshire, along the Chiltern Hills, and especially on the dip-slopes. The accumulation is met with in patches, and less prominently, over the Chalk tracts of Berkshire, Wiltshire, Hampshire, and Sussex; but there is more of it on the North Downs in Kent. Noticeable tracts also occur in Hampshire, south of Odiham and Basingstoke, north of Whitchurch, and onwards to Collingbourne Ducis, in Wiltshire, where there is much woodland.

With regard to the Clay-with-flints in parts of Hampshire, Mr. H. J. Osborne White has observed that, while it is largely made up of débris of Reading Beds, 'it rests indifferently on surfaces which may be 4 or 5 feet, or 400 or 500 feet, below the Eocene basal plane,' and 'may be said to be in process of formation at the present day' under the solvent action of rain. He agrees with Mr. Jukes-Browne 'that much of this deposit, in its present form, is a result of vigorous soil-cap movement, occurring under sub-arctic conditions, during late Pliocene and early Pleistocene times."*

Such downwashes appear to have occurred on the dip-slope of the Chalk, near Caddington, in Hertfordshire, as remarked to the writer by Thomas Leighton.

The plateau loams are used for brick-making; they yield also, at the surface, good yellow loam for gardeners, as on the North Downs at Walton Heath and Banstead.

In the loams associated with the Clay-with-flints on the Chiltern Hills at Walter's Ash, near Hughenden, and other places (see p. 164), large greywethers or sarsen stones occur, also puddingstone, blocks of which may be seen at Bradenham Green. The greywethers are broken up for paving-blocks. Their position is sometimes ascertained by means of prodding the ground with long iron rods. These deposits are evidently a wreck of the Reading Beds and Clay-with-flints, caused, perhaps, by flood-waters arising from the melting of ice during the Glacial Period.†

On the summits of the flat table-lands of the Haldon Hills, in Devon, and here and there on the Blackdown Hills of Devon and Somerset, there are accumulations of rough gravel made up of flint and chert, with quartz pebbles; and at Combpyne, near Lyme Regis, white sands, and white and coloured clays, were seen to be associated with them. These deposits, in the opinion of Mr. C. Reid, represent the accumulations of Eocene rivers. The plateaux of the Blackdown Hills, which include tracts of Chalk as well as Upper Greensand, are covered by more extensive accumulations of flint and chert, in part Clay-with-flints, but largely disintegrated chert of the Upper Greensand. The uplands in general form heaths and commons, with black peaty soils, and clayey matter that holds up ponds.

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* 'Geology of Alresford,' *Mem. Geol. Survey*, 1910; and Jukes-Browne, *Quart. Journ. Geol. Soc.*, 1906, lxii., p. 132.

† H. B. Woodward, *Proc. Geol. Assoc.*, 1905, xix., p. 148.

These mixed plateau Drifts, as pointed out by Mr. W. A. E. Ussher, have been faulted in places, and he expressed the opinion that they may have been, to a large extent, reassorted during the Glacial Period, when 'a great snowfall and very penetrating frosts may at least be invoked.'*

Glacial Drift.

The accumulations spread over the land during the Pleistocene Glacial Epoch, notably in the northern regions of Europe and America, have exercised a most important influence on agriculture, more especially as regards the loamy and clayey drifts.

The Glacial Drift comprises a great variety of materials: stiff, tough, more or less stony clay, with many a large boulder, known as Boulder Clay or Till; gravel and sand, coarse and fine; laminated clays and loams. Land-ice, or ice-sheets, glaciers, icebergs, coast-ice, and streams and torrents on land, resulting from the melting of ice, have contributed to the formation of this mixed assemblage of deposits.

The materials derived from the invasion of land-ice were largely the old soils and subsoils of the weathered land-surface, rubble of all kinds, and relics of soil, being incorporated in the Drift. Hence, some of the earlier Glacial Beds are in mass more oxidized, and in colour reddish-brown; while the later, which were made up of the less weathered strata, are bluish-grey. Hence, also, in glaciated areas, there is not the same depth of weathered subsoil as in those non-glaciated; indeed, the soil has, in places, been cleared away, leaving bare, smooth, polished, and striated surfaces of rock. (See Fig. 41, p. 327.)

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* See H. B. Woodward and W. A. E. Ussher, 'Geology of Sidmouth and Lyme Regis,' *Mem. Geol. Survey*, 2nd edit., 1911, p. 67; and Ussher, *Quart. Journ. Geol. Soc.*, 1878, xxxiv., p. 449.

The enduring qualities of the soil yielded by the less weathered forms of Glacial Till have been commented on by Mr. Merrill (1897, p. 364), who has pointed out that 'the undecomposed feldspathic and other mineral particles contained by the Till, due to its mechanical origin, yield up slowly but continually their supply of plant food.' Lincolnshire and Norfolk have been said to possess almost every variety of soil, and this is largely owing to the various Glacial Drifts.

Originally described by some geologists as 'Extraneous Rubbish,' and by others as Diluvial, the deposits in general, which were recognized to contain travelled blocks, or Erratics, some of which had been transported a hundred miles or more from the parent rocks, were attributed to the supposed universal catastrophe termed the 'Deluge.' Subsequently, when the origin of the deposits came to be discerned, they were termed Northern Drift, and afterwards Glacial Drift.

The Glacial Drifts extend far and wide over Ireland, and over the lowlands and uplands of Scotland, Wales, and the North of England. They cover much of the central plain of England and the Eastern Counties, southwards to the Thames Valley in Essex, and to the northern margin of the Cotteswold Hills. The southern border of the Drift is irregular. Thus there is much Boulder Clay and gravel at Buckingham, and in the vale around Winslow to the south. There is no Drift at Banbury and on Edge Hill, but farther west remnants of Boulder Clay have been found in the Vale of Moreton.

The importance of the Drifts in agriculture is well indicated when we compare the Solid and Drift editions of the Geological Survey maps (scale 1 inch to four miles). In the former edition the greater part of Norfolk and much of Suffolk, is represented as Chalk, and great part of Essex as London Clay; whereas in the Drift edition it is seen that the three counties are extensively covered with various Drift deposits. These were grouped by Joshua Trimmer as 'Erratic Soils.' As previously pointed out, they are truly geological formations, that may attain a thickness of 200 feet or more, and their disintegration has yielded soils of various characters.

To S. V. Wood, jun., we are indebted for the earliest detailed Drift maps of the Eastern Counties. In 1867 he had completed a manuscript 1-inch geological map on the Ordnance Survey (old series) Sheets 1 and 2, the first Drift maps that had been so surveyed in this country. Later on he continued his survey over the Eastern Counties in conjunction with Mr. F. W. Harmer.

Boulder Clay.

What may be termed the characteristic Boulder Clay or Till is a tough, unstratified clay, containing pebbles and subangular stones, and large rounded and angular blocks of rock or boulders, that are often much striated or glaciated. These striations occur on limestones, including hard Chalk, on flint and other siliceous or sandy rocks, and on various igneous rocks. They likewise occur on fossils, such as Belemnites.

Fossils of all ages are to be found in the Boulder Clay of some districts, notably in the Midland and Eastern Counties of England, and in the gravels associated with them.

In colour much of the Boulder Clay is bluish-grey, weathering brown; but sometimes the mass is red, reddish-brown, or purple, the colour, the rock constituents, and the fossils, varying according to the rocks from which the Boulder Clay has been derived.

In the Eastern and Eastern - Midland Counties of

England the Boulder Clay is characterized by an abundance of Chalk, in small pebbles the size of a pea, and upwards to good-sized boulders, and occasionally huge masses.

Among examples of large transported masses are the sheets of Chalk in the Contorted Drift of the Norfolk Coast, the mass at Roslyn Hole, Ely, and that at Catworth, described by Mr. A. C. G. Cameron. At Catworth, near Kimbolton, on the summit of high ground overlooking the plain of the Oxford Clay, there is a mass of Chalk of great size, regularly interstratified with flint, and lying on Boulder Clay. The unusual phenomenon is presented of the greater part of a village built on Chalk far away from any tract where the Chalk formation occurs in place. The evidence is striking. There are ponds in Chalk, the soil in the gardens is Chalk, and the graves in the churchyard leave off in Chalk. There are numerous old excavations besides, whence hundreds of loads of Chalk have been dug out and carted away to the farms adjacent.*

Other well-known examples are the masses of Lincolnshire Limestone at Great Ponton, and the mass of Marlstone 200 yards across at Beacon Hill, described by Professor Judd; while C. Fox Strangways observed a 'mass of Lincolnshire Oolite at least 300 yards long, and 100 yards broad,' to the north-west of Melton Mowbray. All these occur in connection with the Chalky Boulder Clay.

The mode of occurrence of the Boulder Clay is very irregular. It may occur in great sheets of fairly uniform character over large areas of upland in East Anglia, but here and there it descends abruptly into the valleys. The fact is that the pre-Glacial valleys, which became filled with Glacial Drift, have been re-excavated in certain places, fortuitously, along the courses of the present river.

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* *Proc. Geol. Assoc.*, 1894, xiii., p. 356.

At Glemsford, near Long Melford in Suffolk, a thickness of 470 feet of Glacial Drift was thus proved, unexpectedly, in a well-boring; in the Cam Valley, in Essex, a thickness

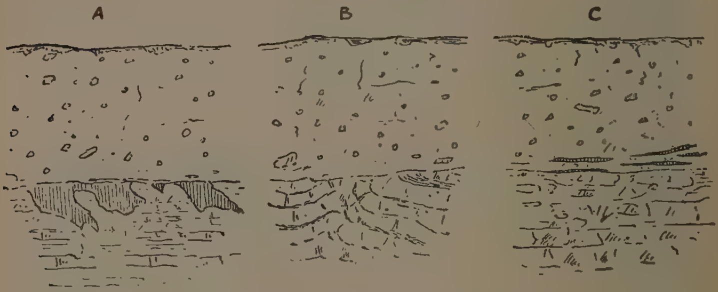

FIG. 24.—SECTIONS ALONG THE GREAT CENTRAL RAILWAY, EAST OF HILL FARM, RADSTONE, NORTHAMPTONSHIRE.

Chalky Boulder Clay resting on Great Oolite.

In this district much of the Great Oolite consists of a soft pale earthy limestone resembling Chalk, and in some places it was not easy to mark any plane of junction between the Boulder Clay and the weathered rubble of Great Oolite. At one point (C) there were streaks of reddish-brown clay at the base of the grey Boulder Clay, and more or less parallel to the bedding of the Great Oolite below. A little farther south the Great Oolite was disturbed and nipped up (B). Again, farther south the Boulder Clay rested on a piped surface of the Great Oolite, the pipes being filled in part with greenish (estuarine) clay, in part with reddish-brown clay precisely like that incorporated in thin strips in Section C. Here evidently the land-ice which accumulated the Boulder Clay was forced over an old weathered land-surface of the Great Oolite. That formation was disturbed in places, and portions of the old soil were stripped off and included, with masses of the rubbly rock, in the Drift. In other places the Boulder Clay was accumulated evenly on the Oolite, the rubbly surface of which was planed off without producing any marked disturbance in the strata beneath.

of 340 feet has been recorded; and in Northumberland and Durham thicknesses of more than 230 feet of Drift have been proved. In these cases the Drift fills old

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* H. B. Woodward, *Geol. Mag.*, 1897, p. 103.

channels that extend below present sea-level, in the case of Glemsford to 347 feet below Ordnance datum, thus affording evidence of great depression of land since the Glacial Epoch.

Examples of some features in connection with the formation of Boulder Clay are represented in Fig. 24.

Tongues of Boulder Clay were sometimes intruded amongst older deposits, as shown in the accompanying section, Fig. 25, noted in 1890.*

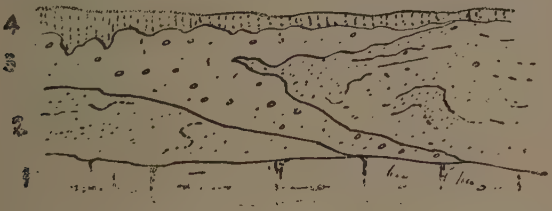

FIG. 25.—SECTION AT CHALK-PIT, CLAYDON, SUFFOLK.

4, Soil and decalcified Boulder Clay.
3, Chalky Boulder Clay.
2, Sands and gravels (Crag Series) disturbed.
1, Chalk.

Total thickness, about 30 feet.

Elsewhere marked contortions of underlying strata are not uncommonly met with where brickearth or clay, or thin alternations of clay and sand, occur beneath Boulder Clay. (Fig. 26.) Sometimes there is evidence of erosion of the underlying clays or Glacial muds, where no contortion was to be seen, as in Fig. 27.

The Chalky Boulder Clay becomes decalcified at the surface in irregular cavities, being piped like the Chalk. (See Fig. 27.) In deep ploughing the unweathered chalky

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* H. B. Woodward, *Geol. Mag.*, 1897, p. 494; see also Whitaker, Geology of Stowmarket,' *Mem. Geol. Survey*, 1881, p. 10.

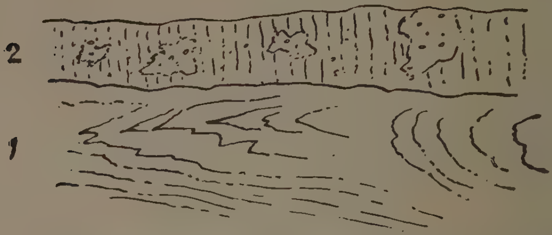
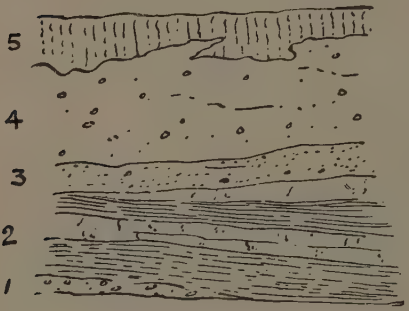


FIG. 26.—SECTION ABOUT ONE MILE SOUTH OF SURLINGHAM ST. MARY, NEAR NORWICH.*

2, Chalky Boulder Clay, mostly decalcified.
Brown stony loam with unweathered remnants of Chalky Boulder Clay, 3 feet.
1, Blue clay and laminated clay and sand, contorted, 5 feet.



5, Soil and decalcified Boulder Clay, 2 or 3 feet.
4, Chalky Boulder Clay, about 5 feet.
3, Chalky sand, 1½ feet.
2, Yellowish laminated clays and bands of marl, 6 feet.
1, Chalky Boulder Clay.

FIG. 27.—PIT NORTH-WEST OF DOVE INN, PORINGLAND, NORFOLK.†

Here we have Glacial muds formed during temporary recession of the land-ice, afterwards overridden by the ice and eroded.

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* H. B. Woodward, *Geol. Mag.*, 1897, p. 492.
† *Ibid.*, p. 493.

portions are here and there turned up. The weathered portions, as near Halstead in Essex, form a strong brown stony and sticky loam or clay that is not naturally fertile. (See p. 111.)

The loamy soil in Essex renders it difficult sometimes to determine whether the subsoil is Boulder Clay or London Clay. There are also tracts of bright sandy loam over the Boulder Clay that appear to be a separate deposit, and not decalcified material. In many cases unweathered remnants of Chalky Boulder Clay may be seen in pits and cuttings in the midst of decalcified stony loam. (See Fig. 26.) It must be remembered, however, that the Boulder Clay was in old times extensively used as a dressing on the land, and remnants may be preserved in the soil. Such appears to have been the case at Hoxne in Suffolk, where the occurrence of traces of Boulder Clay over the Palæolithic brickearth was at one time seen.

In Hertfordshire there is much Chalky Boulder Clay; it constitutes the subsoil of most of Letchworth Garden City, and in Middlesex it forms the higher portion of the residential areas at Finchley.

The Chalky Boulder Clay in general forms the best wheat-land in Essex, and upon it also are grown beans, peas, mangolds, barley, clover, etc. Much of the soil is a rich marly and heavy loam, but not so stiff as the London Clay. The ground has often a park-like aspect, with broad strips of grass-land bordering the roads, and many ponds, excavated in old times as marl-pits, others to supply water for cattle, and even for the human population.

Alternations of Boulder Clay, sand and gravel, loam, marl, and fine laminated clay, may be observed in districts covered by Glacial Drift. In Norfolk such occurrences are well shown in the cliffs between Weybourn and Happisburgh, and so disturbed and contorted are the beds in many places, that inland a gravel-pit and a clay-pit may be opened in close proximity and in fairly level ground. (See Fig. 28.)

Much of the contorted Drift of Norfolk is a brown stony loam, which is seen in a few places beneath the blue Chalky Boulder Clay. It forms highly fertile lands in the north-east of Norfolk and near Norwich, having a soil 2 or 3 feet deep of rich, calcareous, sandy, and somewhat stony loam, which passes westwards into areas of marl. According to Arthur Young (1804), this loamy area constitutes 'one of the finest tracts of land that is anywhere to be seen.'

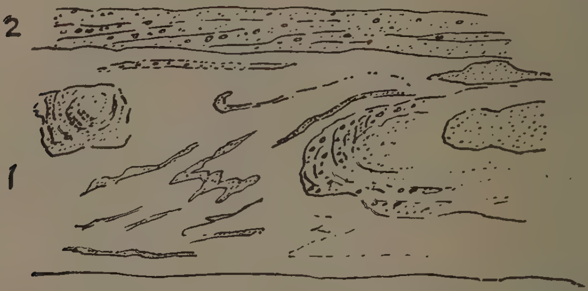

FIG. 28.—PIT BY SPINNY, NORTH-WEST OF THORPE LIME-KILN, NORWICH.*

2, Plateau Drift. Gravel and sand, 3 to 4 feet.
1, Contorted Drift. Stony loam with contorted seams and masses of sand and gravel, 16 feet.

Here the disturbances were produced by the ice-sheet that formed the Chalky Boulder Clay before the Plateau Drift was deposited.*

Alternations of Boulder Clay, sand and gravel, etc., are well seen in the cliffs of Blackpool, Lancashire, in Leicestershire and Derbyshire, Lincolnshire and Holderness in Yorkshire, at Criccieth in Carnarvonshire, and many other places. The term 'rammel' is locally applied to Boulder Clay in Leicestershire and Warwickshire, and 'pinel' in Lancashire.

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* H. B. Woodward, *Geol. Mag.*, 1897, p. 490.

Varieties of Drift that form a kind of passage between stiff Boulder Clay and gravel occur in Cumberland, Glamorganshire, etc. They consist of a stony earth or earthy gravel, that yields a soil much lighter than that of Boulder Clay.

Sometimes the soil affords a strong indication of Drift, when adjacent pits or quarries show but little trace of it. In Warwickshire, near Rugby, Daventry, etc., there is a thin mantle of reddish-brown sandy soil and subsoil, containing many quartzite and quartz pebbles, derived from the Bunter pebble-beds; sometimes there is only a scattering of pebbles on the Keuper Marls, or Lias Clays; elsewhere a heavy Drift Clay with quartzite pebbles.

In Derbyshire, as remarked by Mr. E. M. Wrench, the deposition of Drift from the Derwent glacier 'has favoured the growth of the oak and beech forests that so long harboured wolves in the Middle Ages.'*

In Cheshire the areas of Boulder Clay are mostly pasture-land, while the sandy Drift deposits are under arable cultivation.

Stiff and clayey Boulder Clay occurs in Skye and on Raasay, where Lias Clays yielded the material, while a more reddish loam or sandy clay has been derived from the basalt areas. Tracts of pasture-land and ground cultivated for oats and potatoes occur on the Drift.

In Caithness the Boulder Drift occurs over extensive tracts, giving rise to peaty and sloppy moors, with few rock exposures, and many lochs with grassy margins.

In Sutherland the limit of cultivation along the Old Red Sandstone hills of the Eastern Coast is marked by the Boulder Clay, and often by springs thrown out along its upper limits, where it is banked against the older rocks.

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* *Journ. Manchester Geograph. Soc.*, 1908, xxiv., p. 1.

Aberdeenshire owes its agricultural eminence largely to the coverings of Drift in the eastern part of the country. Much of it, as described by Mr. T. F. Jamieson, is clay covered by gravel. The clay is brown, bluish-grey, and brick-red in colour, containing boulders and stones in some areas, but in many parts free from them. On the lower grounds bordering the coast there is a good deal of clay, stony earth, sand, and gravel, in places 100 feet thick. In other parts of eastern Scotland there are fertile loamy soils due, in part, to Glacial Drift, and in part to the débris derived from the Old Red Sandstone and other formations. (See p. 68.)

The gravelly and sandy Drift in the north-west Highlands is not as a rule fertile.

In Ireland the Boulder Clay varies much according to the strata from which it has been formed. That in Antrim, derived in part from basalt, yields a stiff retentive soil adapted for pasture-land, while much of the Drift derived from Silurian rocks is stony and sandy clay.

In Ireland the detritus of limestone distributed in Boulder Clay and gravels over many parts of the country, especially in the Great Central Plain, has been of essential service in giving rise to rich brown and fertile loams. This Drift passes locally into non-calcareous deposits. The Curragh in Kildare is an open undulating grassy and gorsy tract of Boulder Drift, sand, or gravel.

Large boulders found in deep ploughing in areas of Boulder Clay have been removed, and in some instances placed in pasture-lands as rubbing posts, where they become polished by sheep, and in other cases they have been removed to the corners of houses for protection.

It has been recorded that the lowland parts of Aberdeenshire, now highly cultivated, were formerely covered with countless blocks of granite, gneiss, and other rocks. These have been mostly cleared away, some being sent to London for paving material, others locally used for stone-walls, and many were taken to form the great 'Consumption' Dyke, nearly half a mile long, at Kingswells, near Aberdeen.*

Perched blocks distinct from tumbled masses of rock occur in glaciated regions, left by melting of the ice, and sometimes, as at Thirlmere, they are rocking-stones.

Again, mounds of Boulder Clay, described by M. H. Close as straight and parallel ridges three-quarters of a mile long, and up to 100 feet or more in height, known as 'drumlins,' are conspicuous in Counties Clare, Eastern Mayo, Sligo, and Southern Donegal, and also in Scotland.

Plateau and Glacial Gravels and Sands.

Gravels and sands at higher levels than the ordinary valley deposits or river gravels are grouped as Plateau and Glacial Drift. The deposits vary in thickness from a few feet up to 100 feet, and are mostly devoid of calcareous ingredients.

Some of the gravels are of very pebbly character, being made up of flint and quartz pebbles, as on the higher grounds along the borders of Middlesex and Hertfordshire. The gravel is sometimes but 1 to 3 feet thick. It rests on London clay, and has a rather clayey matrix, so that, as at Totteridge and on Stanmore Heath (see Fig. 31), there are numerous ponds. Other tracts occur at Wimbledon and Oxshott Heath in Surrey.

In Berkshire, Oxfordshire, Buckinghamshire, Hertfordshire, and Middlesex, the Plateau gravels have given rise to numerous picturesque commons, and at Cadmore and

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* A. Mackie, 'Aberdeenshire' (Cambridge County Geographies), 1911, p. 6.

Lane End, Gerrard's Cross, Beaconsfield, Watford (Fig. 31), Rickmansworth, Croxley Green, Harefield, Radlett, etc., to localities that make good residential sites.

In Norfolk there are very coarse gravels, termed 'cannon-shot gravels,' by S. V. Wood, jun. They occur at Mousehold Common, Norwich, Poringland, Holt, etc. In the south-east of Norfolk, near Haddiscoe, and in north-east Suffolk, near Fritton, Oulton, Pakefield, Halesworth, Westleton, and Dunwich, there is a good deal of pebble-gravel in the Glacial Drift, which in some parts is mostly formed by sand. The pebbly gravel has been termed the 'Westleton Shingle,' but in the same district there is pebbly gravel of the Norwich Crag Series, and where the two come together it is not easy to separate them. The newer gravel occurs in the higher part of Dunwich Cliff, the older or crag gravel at Southwold, and the two are probably present at Westleton Common.

In Suffolk three main divisions have been made in the character of the land:

1. Western, the *Fieldings*, where there is but a light, sandy soil, on Chalk, with occasional gravelly patches—a poor soil liable to be wind-drifted, and giving rise to many heaths and warrens. (See p. 113.)

2. Central, the *Woodlands*, with a subsoil of Chalky Boulder Clay, as around Framlingham, Debenham, Mendlesham, Eye, and Botesdale.

3. Eastern, the *Sandlings*, where the Crag Series and Drift sands and pebble-beds are developed in a tract extending from Woodbridge to Orford on the north, and Bawdsey on the south.

The same general divisions apply to some extent in Norfolk. In the west we have the Chalk with thin, sandy and flinty loam soils, extending over the heaths of Croxton, Larling, Roudham, and Wretham, to Watton. (See p. 131.) In the central areas there is much Chalky

Boulder Clay, and in the east lighter loams, Drift sands, and gravels, and areas where the Crag is exposed.

Portions of south and south-west Norfolk, largely heath and warren, are known as the 'Breck District,' and were thus described by H. Stevenson: 'The greater part of this district consists of what are locally called "brecks"—that is, ground which at some time or other has been "broken up" by the plough.' Many of the brecks or large fields, 'never very fertile to begin with, through bad farming and consequent exhaustion of the soil, have long been abandoned as arable land, and are now used as sheep-walks; but others form, in many cases, commons or heaths, on which the hasty observer would never recognize the trace of a plough.' At the same time there are 'some extensive tracts, which have, probably, never been under cultivation.'* Until about 1838 the Breck District was the haunt of the great bustard.

In Holderness, as observed by Mr. C. Reid, most of the gravel-lands have a loamy soil 1 to 2 feet deep, furnishing good soil for barley and oats. He considers that a good deal of clayey material is wind-drifted, clayey particles being derived from exposed portions of Boulder Clay, and thus loamy soils are formed on areas of sand and other subsoils.†

In southern Scotland certain mounds and ridges of Glacial sand and gravel are known as 'kames' ('kaims') or 'green hills,' because their slopes not infrequently 'are carpeted with fresh green turf, in strong contrast to the more sombre-hued vegetation of the surrounding clay-covered tracts.'‡

In Aberdeenshire the Kippet Hills, by the Loch of Slains, are kames that are 30 or 40 feet high.

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* 'Birds of Norfolk,' 1866, vol. i.

† 'Geology of Holderness,' *Mem. Geol. Survey*, 1885, p. 118.

‡ Professor J. Geikie, 'Great Ice Age,' 2nd edit., 1877, p. 212.

Along the eastern borders of Sutherlandshire many similar gravel hills rise from plains of alluvium and Boulder Drift; they are usually gorse-covered, and contrast with the surrounding cultivated grounds.

In Ireland the gravel ridges are known as 'eskers,' and they are prominent in many parts of the Central Plain.

Somewhat similar gravel hills occur in Cumberland, west of Carlisle, and in West Norfolk.

The more irregular mounds of gravel and sand in glaciated regions are usually described as 'moraines.'

Some of the Glacial sands and gravels, notably in East Norfolk and Suffolk, contain masses of more or less broken Crag shells, being to a large extent re-deposited Crag. Elsewhere Pleistocene mollusca occur in the sands and gravels, but some of these have been much disturbed and upraised by Glacial action to high elevations, as east of Macclesfield to 1,200 feet, and at Moel Tryfaen, south-east of Carnarvon, to 1,360 feet.

CHAPTER XIX

GEOLOGICAL FORMATIONS (*Continued*).

2. TERTIARY

PLIOCENE.

THE Pliocene deposits in England include the following subdivisions:

Cromer Forest Bed Series.
Norwich Crag Series.
Red Crag.
Coralline Crag.

Cromer Forest Bed and Crag Series.

The Cromer Forest Bed Series is practically confined to the coast between Weybourn in Norfolk, and Kessingland in Suffolk, where it occurs beneath the Glacial Drifts. It consists of laminated clays and peaty beds, sands and gravels, that attain a thickness of from 20 to 30 feet. Lumps of amber occur in the strata, and on the foreshore of the Cromer coast. In the opinion of Mr. C. Reid they have probably been derived from an extension beneath the North Sea area of the amber-bearing beds (Upper Eocene or Oligocene) of the Baltic shores of Prussia.

The Crag deposits consist for the most part of shelly sands and gravels, occasionally indurated. The shell-beds have been used as a dressing for land, and as material for garden walks; but the name Crag was probably in the first instance applied to the comparatively hard layers of sandy limestone that occur in the Coralline Crag, and have been used as building-stone. These beds are sometimes piped through dissolution of calcareous matter, and the shell-beds in the Crags are locally decalcified so as to leave apparently unfossiliferous sands and gravels that cannot always be readily distinguished from some Glacial Drifts.

The Norwich Crag Series, about 30 feet thick where exposed, is for the most part a pale buff or ochreous shelly sand, with pebbly layers, and at the base a stone-bed resting on the Chalk, and made up of partially rolled flints. The shell-beds are of local occurrence, their absence in some places being due to dissolution. The lower strata of the series are usually grouped as the fluvio-marine Crag. At a higher horizon 'jambs' of clay (Chillesford Clay) locally occur interlaminated with white and brown sand at Chillesford, Aldeby, Surlingham, Wroxham, etc., and the beds are worked for brick-making. The upper strata usually consist of pebbly gravel (Bure Valley Beds) with local shell-beds, and casts of shells in ironstone or iron-pan, also many ochreous nodules. The Weybourn Crag belongs to this horizon. The soils are mostly light, sandy and gravelly; and sometimes shelly layers are turned up by the plough.

The Red Crag, as its name implies, is usually of a reddish-brown colour, and is remarkably current-bedded; it consists largely of ferruginous shelly sand, 25 to 40 feet thick as a rule; but, like the Norwich Crag, much greater thicknesses have been proved in well-borings, and then the Crag is usually blue or grey in colour. At its base there is found in certain tracts a layer composed largely of phosphatic nodules, 6 inches to 3 feet thick, and worked formerly at Felixstow, Walton, Falkenham, Ramsholt, Sutton, Boyton, and other places. This layer was probably derived from the similar bed, known as the Suffolk Bone Bed, which occurs at the base of the Coralline Crag. The Rev. J. S. Henslow, in 1843, was the first to call attention to the occurrence of these phosphatic nodules at Felixstow, and his discovery led to the establishment in this country of the so-called 'Coprolite' industry. (See p. 136.) Moreover, he two years later found similar nodules in the basement Chalk or Cambridge Greensand that proved of great economic value.

The Red Crag yields a light, sandy, and calcareous loamy soil.

The Coralline Crag is well seen near Aldeburgh, Orford, Sudbourne, and Ramsholt in Suffolk, occupying comparatively limited areas. It consists of pale buff soft calcareous sands, for the most part very shelly, and with harder bands that have been used as building-stone. The thickness varies from 40 to about 80 feet. At the base at Sutton, as in the Red Crag, there is a bed with phosphatic nodules, and water-worn teeth and bones of mammalia, also teeth of sharks and remains of crustacea (derived from the London Clay). The soil on the Coralline Crag is a calcareous and sandy loam.

Lenham Beds.—Filling irregular cavities or pipes in the Chalk of the North Downs, at Lenham near Maidstone, Paddlesworth north-west of Folkestone, and at Headley and Netley Heaths in Surrey, there have been found yellow sands, clays and ferruginous sandstone, yielding at Lenham and some other localities Pliocene fossils. The beds may indicate a somewhat earlier stage than the Coralline Crag, and be equivalent to the Diestian of Diest in Belgium.

St. Erth Beds.—Beds of clay and quartzose loamy sand, known as 'growder,' yielding Pliocene fossils, were discovered in 1882 at St. Erth, north-east of Penzance. The shells occur in blue clay, and appear to represent the same horizon as the Lenham Beds. The sand has been found useful for moulding purposes. The Lenham and St. Erth Beds occur over such limited areas that they do not affect the agricultural character of the land.

OLIGOCENE.

This system is almost wholly confined to the Hampshire Basin, the Isle of Wight and portions of Dorset and Hampshire, the exception being in the Bovey Beds of Devon. It is, however, not improbable that some of the Tertiary volcanic rocks of the north-east of Ireland and the Inner Hebrides may be of Oligocene Age.

The following are the stratigraphical subdivisions:

Bovey Beds.
Hamstead Beds.
Bembridge Limestones and Marls.
Osborne Beds.
Headon Beds.

The Oligocene is a fluvio-marine series, consisting of sands, loams, white, black, purple, blue, green, and red clays, marls, and occasional beds of thin limestone in the Headon and Osborne Beds, more prominently in the Bembridge Beds. Most of the strata are shelly. The Nettlestone grits in the Osborne Beds have been used for building purposes, and also the Bembridge limestone, which has been quarried at Sconce, Quarr Abbey near Binstead, and near Ryde. The clays at various horizons have been worked for brick-making. The soils are mixed, and, owing to the alternation of pervious and impervious bands, many springs occur; but the land, when drained, is fertile.

The *Bovey Beds* of Bovey Tracey and Newton Abbot in Devon were assigned by Pengelly and Oswald Heer to the Miocene Period. They were subsequently grouped with the Lower Bagshot Beds by J. S. Gardner, and they have recently been placed in the Oligocene by Mr. and Mrs. Clement Reid, who remark that 'we cannot yet find in Britain true Miocene deposits, but the Bovey plants show that we have representatives of the very top of the Oligocene.'*

The beds consist of white, grey, and coloured clays, sands coarse and fine, gravels, and beds of lignite; and, as proved by boring, they attain a thickness of more than 520 feet. The clays are largely dug near Newton Abbot for potters and pipe-clay, mostly shipped at Teignmouth for the Potteries; hence the beds are sometimes termed 'Teignmouth Clay.' Locally, fire-bricks, glazed bricks, and all kinds of sanitary ware are manufactured at Heathfield. The lignite, or brown coal, has been dug extensively at Bovey Tracey, and more recently between Newton Abbot and Chudleigh. One seam of the 'Bovey coal' is 6 feet thick.

The area over which the Bovey Beds occur is largely covered by a gravelly deposit or Head, in part river gravel

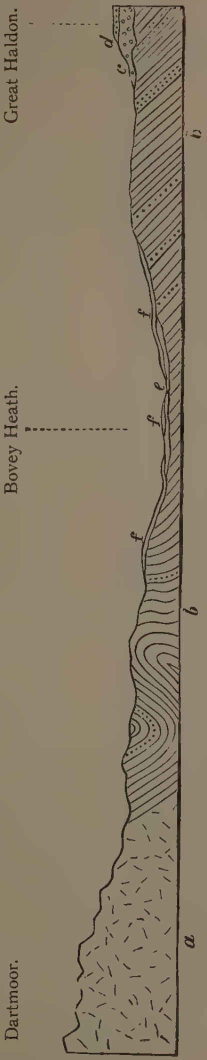

FIG. 29.—GENERAL SECTION FROM DARTMOOR TO GREAT HALDON, DEVON.

b, Culm Measures. d, Upper Greensand. f, Valley Gravel.
a, Granite. c, Permian Breccia and Sandstone. e, Bovey Beds.

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* *Phil. Trans.*, 1910, cci., p. 162.

and in part re-arranged Bovey gravels, and also by alluvium. The ground is a heathy tract and by no means fertile. (See Fig. 29.)

EOCENE.

This system is divided as follows:

Bagshot Series.
London Clay.
Oldhaven and Blackheath Beds.
Woolwich and Reading Beds.
Thanet Beds.

The Eocene formations occur in the London and Hampshire Basins, with the exception of the Thanet Beds and Oldhaven and Blackheath Beds, which are met with only in the London area.

Bagshot Series.

This series admits of the following subdivisions:

Upper Bagshot Beds { Barton Sands.
{ Barton Clays.
Bracklesham Beds.
Lower Bagshot Beds.

In the London Basin the Barton Clays are not distinguished, but all the above subdivisions are present in the Hampshire Basin.

The Barton Sands consist of white and yellow sands, and are well-developed at Headon Hill in the Isle of Wight, and on the Hampshire mainland.

The Barton Clays consist of grey and greenish shelly clays, well exposed in the cliffs of Barton in Hampshire.

The Upper Bagshot Beds of the London Basin, probably equivalent in age to the Barton Clays, consist mostly of buff and white sands, but locally some flint pebble-beds may be grouped with them. Greywethers occur in the sands and also in superficial gravels on the Frimley Ridges in Surrey.

The Bracklesham Beds consist of grey, lilac, and greenish (glauconitic) clays, loams, marls, and sands, with a good deal of lignite and ferruginous matter; and they are often very shelly, as in Bracklesham Bay, Sussex, where the strata are exposed on the foreshore. Near Weybridge and Addlestone in Surrey the clayey beds occupy basin-shaped hollows excavated in the Lower Bagshot Beds.

The Lower Bagshot Beds in the London area consist of buff sands, with seams of pipe-clay; the sands are often very fine and mealy. Pebble-gravel occurs at Brentwood and Warley in Essex. The sands cap the prominent hills of Harrow and Hampstead, Langdon Hill and Rayleigh, and occur over extensive areas in Surrey. In the Isle of Wight they are well exhibited in Alum Bay, and on the Hampshire mainland at Bournemouth and Poole, where the strata include variously coloured sands, beds of white and coloured clay, and grey laminated clays. In their extension into Dorset the formation is represented by much pebbly, sub-angular, and mixed gravel, as on Bincombe Down and Blackdown, near Portesham, where the beds have been spread over a large irregular area by downwash.

Taken as a whole, the Bagshot Series is naturally unproductive, comprising, with overlying plateau gravels, large tracts of open heath-land and common, waste and scrubby tracts, much wood-land with firs in Surrey, Berkshire, Hampshire, and Dorset, interspersed in some areas with arable and grass lands.

The soils on the Upper and Lower Bagshot sandy strata are naturally the more barren, as there is a general absence of lime, and iron-pan is sometimes encountered in the subsoil.

The Bracklesham Beds, in the heath-lands, give rise to wet and marshy tracts, with ponds; but where well drained, they form the best land for cultivation, with good loamy soils.

The white Headon Hill sands, in the Isle of Wight, have been much used for glass-making.

The white and other clays of Poole and Wareham, and those of West Wellow, south-west of Romsey, have been extensively worked for pottery and other purposes.

The loams of the Bracklesham Beds and the Barton Clay, where not too shelly, and some clay beds in the Lower Bagshot, as at Ramsdell, north-west of Basingstoke, are used for brick-making.

The gravels, as on Blackdown, Portesham, are largely dug for road-metal, and the greywethers of the Bagshot area in Surrey have been used for paving and building purposes, gate-posts, etc.

Some of the sands of the Bagshot Beds are very fine, and rain does not readily percolate.

Good residential areas occur on the higher grounds of Surrey, around Woking, Weybridge, Esher, and Egham; in Berkshire, at Ascot, Sunninghill, and other localities; on the borders of Hampshire, at Aldershot, etc., also at Southampton and Bournemouth; and at Brentwood, Warley, High Beech, and elsewhere in Essex.

London Clay.

This is, for the most part, a stiff clay, brown at the surface, mottled blue and brown as a subsoil, and bluish-grey at a farther depth. Bands of septaria, or cement-stones, formerly used for the manufacture of Roman cement, occur at various horizons in the London Clay.

Both upper and lower portions are more or less sandy.

The higher beds pass upwards gradually, or by alternation of sand, loam, and clay, into the Bagshot Beds, as near Brentwood and Epping, and Claygate in Surrey. The lower, or basement, bed, is sandy and pebbly, with sometimes hard layers of shelly, more or less calcareous, sandstone.

In Suffolk, where the London Clay is exposed mainly on the slopes of valleys, the soil has been described as a rich loam, being lightened and improved by downwash from bordering sandy and gravelly tracts.

The mass of the London Clay, otherwise, yields a stiff, tenacious, and intractable soil, deficient in lime; it soaks up a good deal of water, and shrinks and cracks in very dry weather; therefore, as mentioned (p. 172), foundations are by no means stable in many cases. There are residential areas at Hampstead, including its garden suburb, at Harrow, Edgware, and Willesden, to the north of the Thames; and at Claygate, Malden, Surbiton, much of Wimbledon, Streatham, Penge, Sydenham, and other places to the south of the river. Elsewhere there is much meadow and pasture land, with some woodland, and especially oak-forest, as at Epping. The London Clay forms a good tile-earth, and is largely used for brick-making, in most cases with an admixture of sand.

Oldhaven and Blackheath Beds.

The name Oldhaven is taken from Oldhaven Gap, west of Reculvers, on the Kentish coast, where the beds consist mostly of fine, light-coloured, quartzose sand; whereas on Blackheath they are represented largely by beds of flint pebbles in a sandy matrix, occasionally cemented into a puddingstone, as near Croydon. These pebble-beds rest sometimes on an eroded surface of the Woolwich and Reading Beds. (See Fig. 30.)

The Blackheath Beds form, as a rule, good sites for residences when well developed, as in the uplands of Blackheath, Welling, Bexley, Sidcup, Chislehurst, Beckenham, Bromley, West Wickham, and Hayes. The pebble-beds are dug in places for concrete.

Woolwich and Reading Beds.

This is a mixed formation of variously coloured clays, grey shelly clays, loams, white, green, and crimson sands, with pebble-beds formed almost wholly of flint; and large concretionary masses of sandstone or greywethers, examples of which were well exposed on the Great Central Railway near Gerrard's Cross, south-east of Beaconsfield.

The Woolwich Beds comprise the strata that occur in East London and North Kent. In the north-eastern part of Kent the beds consist mostly of pale, false-bedded sand, with marine shells; westwards there are intercalated clays with estuarine fossils, that occur in Kent and East Surrey, also in South Essex.

The Reading Beds extend over areas to the north, north-west, and west of the tracts before mentioned, but there is no real division between the two types, as they pass gradually one into the other; and an oyster-bed occurs in the lower part of the formation in Berkshire.

The red and mottled plastic clays are extensively worked for brick-making at Reading and many other localities; fire-bricks have been made at Ewell; glass-sands have been obtained at Pinner and other localities, sometimes by shafts; and other beds of sand have been used for mortar-making.

In parts of Hampshire the formation is almost wholly clay, or with thin, sandy beds near the base. The clay, as noted by Mr. C. Reid, forms a cold, wet soil, and the sand is apt to cause the crops to dry up and 'burn.' Stamshaw Clay, near Hilsea, north of Portsmouth, has been used for puddling purposes. Red bricks, etc., are

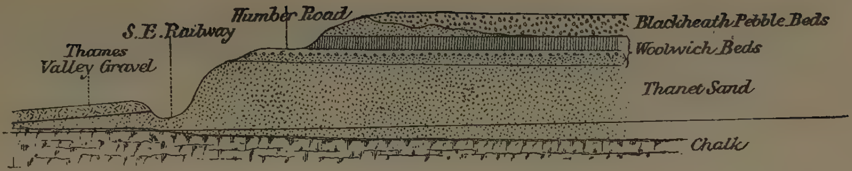

FIG. 30.—SECTION ACROSS WESTCOMBE PARK, GREENWICH. (T. V. Holmes.)

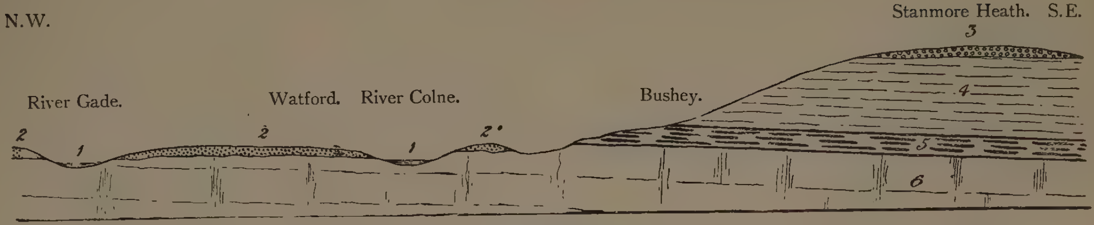

FIG. 31.—SECTION THROUGH WATFORD AND BUSHEY, HERTFORDSHIRE. (Length about 6 miles.) (W. Whitaker.)

3, Pebble Gravel.
4, London Clay.
5, Woolwich and Reading Beds.
6, Chalk-with-flints.

1, Alluvium.
2′, Brickearth } Glacial Drift.
2, Gravel

made at Fareham from Reading Beds and London Clay.

It is probable that the greywethers, Druid sandstones or Sarsen stones, of the Wiltshire and Berkshire Downs, are relics of Reading Beds, which formerly extended over the area; and perhaps also those in the 'Valley of Stones,' in Bride Bottom, near Portesham, in Dorset. By the horse-trainers of Lambourn the scattered greywethers are looked upon as a nuisance, and the blocks are being steadily removed to be broken up for paving-setts. (See p. 217.)

Some of the greywethers contain flint pebbles. The pebble-beds also are cemented into a hard conglomerate, known as the Hertfordshire puddingstone, examples of which may be seen *in situ* about three-quarters of a mile east of Radlett Railway Station. Most of the examples of puddingstone have, however, been obtained from the Plateau Drifts.

The soils on the Woolwich and Reading Beds are naturally variable: stiff clay in some places, light loam and sand elsewhere, gravelly in other places.

Good residential sites may be found at Radlett, Bushey, near Watford (Fig. 31), Northwood, Pinner, Ruislip, Gerrard's Cross, and in parts of Surrey and Kent. In some of these localities the strata are partly concealed by coverings of gravel.

Thanet Beds.

This group consists of fine and firm pale grey and greenish sands, somewhat loamy in parts, and occasionally containing indurated masses of sandstone. At the base there is usually a stony layer, known as 'bull-head,' probably on account of the irregular, unworn, and green-coated flints of which it is mostly composed.

The beds are well seen in extensive pits at Crayford and

Erith, where they stand with almost vertical faces. The sands yield some of the best moulding material for iron-furnaces. Fire-bricks are made at Beddington.

The soils are light, sandy, and productive, fruit and hops being cultivated in Kent.

The outcrop of the strata in Surrey is mostly narrow from Leatherhead to Croydon, but good and dry sites for residences are usually to be found, and this would be the case more particularly in the larger-exposed areas in North Kent. The Thanet Sands occur at Sandwich and on the shores of Pegwell Bay.

CHAPTER XX

GEOLOGICAL FORMATIONS (*Continued*).

3. SECONDARY OR MESOZOIC (CRETACEOUS)

This system comprises a variety of formations, with many local divisions, the whole surmounted by the comparatively uniform Chalk.

The main divisions are as follows:

Chalk.
Upper Greensand } Selbornian.
Gault }
Lower Greensand.
Wealden.

Chalk.

Taken in mass, the Chalk is one of the most uniform of geological formations in England, extending over large areas, being easily recognized, and attaining a great thickness.

For practical purposes it has been divided as follows (see Fig. 32):

	Thickness in Feet.
Upper Chalk with many flints: Chalk Rock at base	600 to 1,370
Middle Chalk with few or no flints: Melbourn Rock at base	100 to 200
Lower Chalk with, in lower part, Totternhoe Stone (local), Chalk Marl	100 to 215

These three main subdivisions are now shown on the Geological Survey maps. If we glance at a geological map on a small scale it will be observed that the Chalk is represented in broad tracts from Flamborough Head to the Humber, and southwards to Louth and Alford, forming the Wolds of Yorkshire and Lincolnshire; again, it extends from western Norfolk and Suffolk to the Gog-magog Hills of Cambridgeshire, the Luton and Dunstable Downs, the Chiltern Hills, Ilsley and Marlborough Downs, Salisbury Plain, and the Dorset Downs. East of Winchester it becomes divided into the North and South Downs, which extend respectively to Dover and Beachy Head. (See Fig. 35, p. 265.)

There are minor tracts in the Isle of Wight, at Seaton and Beer in Devon, and in the north-east of Ireland.

The higher beds of Chalk are characterized by abundant flints in

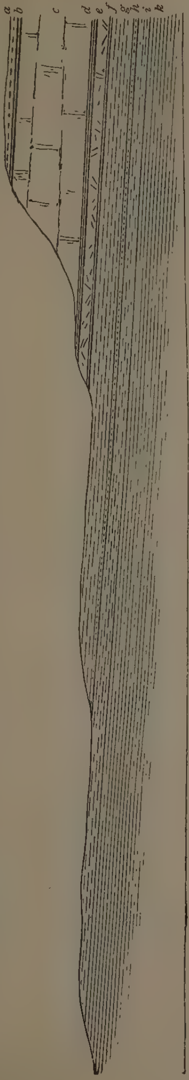

FIG. 32.—GENERAL SECTION NEAR PRINCE'S RISBOROUGH, BUCKINGHAMSHIRE. (W. Whitaker.)

Longitudinal scale, 3 inches = 1 mile. Vertical scale exaggerated.

a, Chalk-with-flints } Upper Chalk.
b, Chalk Rock
c, Chalk with few flints } Middle Chalk.
d, Melbourn Rock
e, Marly and blocky Chalk } Lower Chalk.
f, Totternhoe Stone
g, Chalk Marl
h, Clayey Greensand } Upper Greensand.
i, Calcareous sandstone
k, Gault.

nodules and tabular layers, and with sometimes oblique veins of flint. Immense flints, often pear-shaped, known as 'paramoudras,' or 'potstones,' occur in the Chalk of Antrim, Norfolk, and occasionally elsewhere. Nodules of iron pyrites, with radiated structure, popularly known as 'thunderbolts,' are not uncommon in some localities.

The Upper Chalk is one of the purest forms of limestone, consisting almost wholly of calcium carbonate.

The Chalk Rock, known in Hertfordshire and Bedfordfordshire as 'hurlic' or 'hurlock,' is a compact Chalk, with hard, green-coated nodules; and the Melbourn Rock is of somewhat similar character. Some of the lower beds in Dorset and Devon are arenaceous, and contain quartz grains or tiny pebbles.

The characteristic features of the Chalk are the bold, rounded features of the uplands (downs and wolds). There, as a rule, few trees occur, but there is fine natural pasture of short and sweet herbage, thin hedgerows, and large fields; and the ground is devoid of running water, except in the deeper valleys. Dew-ponds afford drinking-water for sheep. (See p. 182.) The turf is appreciated by horse-trainers, who have establishments on the downs, and the race-courses of Goodwood, Epsom, Newmarket, and others, are also situated on these areas.

The smooth, open features prevail along the escarpments, and more prominent hill-ranges, over the Marlborough Downs and Salisbury Plain, the crests of the North Downs, and wider areas of the South Downs.

Where there are no coverings of superficial deposits, the natural soil on the Chalk, excepting over the lower marly strata, is sometimes hardly perceptible over a chalk-pit, when an adjacent ploughed field has a brown, loamy appearance. The actual soil, but a few inches thick, consists of friable, chalky, or marly loam, with a few flints and a little humus.

In many places the subsoil is formed of a rubble of chalk and earth, when the firmer beds of Chalk have been broken up and weathered into rounded forms like pebbles. (See Fig. 3, p. 38.)

The Chalk itself is sometimes soft and putty-like when wet, giving rise to sticky subsoils.

On the steeper slopes, of an angle of not more than 15 degrees, where the Chalk is under arable cultivation, the ploughed fields show pale grey chalky soil, passing on lower and gentler slopes into darker or brownish-grey soil. (See Fig. 7, p. 77.)

The ground on the lower slopes, where the soil is deeper and under arable cultivation, is locally known as 'puffy land.'*

Again, the lower and gentle slopes below the Chalk escarpments, where the Chalk Marl is developed, yield fairly heavy marl, or malmy soil, a productive belt, known in some parts as 'white land,' the cultivation of which differs generally from that of the mass of the Chalk, there being good arable land for corn, beans, etc. In Bedfordshire the village of Barton-in-the-Clay is situated on this white land of Chalk Marl.

In certain areas considerable changes have been made: thus the northern part of the Yorkshire Wolds, at one time given up wholly to sheep-pasture, is now under arable cultivation.

On the Lincolnshire Wolds, as remarked by Mr. C. Reid, the thin soil over the Chalk in certain areas is so slightly calcareous as to require marling or chalking, and shallow pits have been opened in the middle of fields to supply the top-dressing, and afterwards ploughed over.† The soil on which barley is cultivated is a very sandy and flinty loam, often less than 6 inches thick; this is due partly to wind-drifted material. At the same time, on ploughed lands soil is removed by the wind.

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* E. A. Rawlence in 'Report of the Royal Commission on Coast Erosion and Afforestation,' vol. ii., part ii.

† 'Geology of Holderness,' *Mem. Geol. Survey*, 1885, p. 119.

In Hampshire, where much of the Chalk area is under arable cultivation, the soil is of variable depth, though but little is to be seen in some of the railway-cuttings near Winchester. The undulating country, however, has a pleasing mixture of woodland and pasture.

Nevertheless, throughout much of the Chalk area, from the Yorkshire Wolds to the Chiltern Hills, also along the North Downs in Surrey and Kent, and especially over the dip-slopes, the Chalk is largely covered by superficial deposits of Boulder Clay (north of the Chiltern Hills), gravel and sand, Clay-with-flints, and loam or brickearth, and here and there outliers of Reading Beds, or rearranged masses of them. In consequence, the agricultural character of the land is much modified: the down-lands occupied by sheep are replaced by arable and wood lands, and streams appear.

If the hill-tops are capped by gravel and sand, the slopes show a mixed soil of grey marly loam, chalk rubble, and patches of rough flint gravel; and deep, gravelly soils occur in the dry upland valleys. (See Fig. 17, p. 212.)

On some of the light lands in Western Norfolk flints, mostly bleached, were so abundant in places that they were picked off the land once in four years, to the amount of about two loads per acre.*

The Chalk (as noted, p. 98) can absorb a good deal of water, and when little rain falls, the soil, though it may become superficially dry, is seldom parched, as the Chalk subsoil retains a certain amount of moisture.

As a formation the Chalk is one of the chief sources of water-supply in England. Fine springs of clear and bright water break out from the Chalk where the combes have been eroded to the plane of saturation ; and elsewhere, above the more clayey and impervious beds of Chalk Marl, especially from the Totternhoe Stone in Cambridgeshire and Bedfordshire. Such situations, and along the courses of the streams to which the springs give rise, are favourable for the establishment of water-cress beds, and there are many in the counties just mentioned, and those of Hertford, Buckingham, Berks, Wilts, and Hants. Great care has to be taken that the waters and the workers are free from sources of pollution.

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* C. B. Rose, *Phil. Mag.*, series 3, 1835, vii., p. 195. One load amounts to 24 bushels.

The phosphatic nodules of the Lower Chalk ('Cambridge Greensand'), and the phosphatic Chalk of Taplow, are elsewhere described. (See p. 137.) There is also a phosphatic bed with phosphatized fossils which was formerly dug at the base of the Chalk at Farnham and Alton. The lower beds of Chalk, especially the Chalk Marl, are utilized in the manufacture of lime and cement, as at Church Knowle west of Corfe Castle, at Bramber near Shoreham in Sussex, at Betchworth and Dorking, at Arlesey in Bedfordshire, and at Bottisham and Shepreth in Cambridgeshire. The Middle and Upper Chalk are burnt for lime, but naturally do not yield so strong a material.

Portland Cement is manufactured from the higher beds of Chalk mixed with river mud, or Gault Clay, notably along the Medway Valley at Halling above Rochester, also at Northfleet, Grays, etc., and at Burgh Castle, west of Gorleston, in Suffolk. Whiting is also prepared in many localities. Some of the harder beds of the Chalk have been utilized for building-stone, especially for inside work.

The Beer Stone at the base of the Middle Chalk has thus been worked at Beer near Seaton in Devon. It contains 3 or 4 per cent. of silica. On about the same horizon the Totternhoe Stone has been worked in Bedfordshire, also at Burwell and Reach in Cambridgeshire, where it has locally been termed 'Clunch.' In West Norfolk, at Marham, building-stone has been obtained from hard beds in the Lower Chalk.

Near Norwich many old workings with galleries have been found in the Chalk, made for the purpose of extracting Chalk or fresh flints. One of these was found in 1823, near St. Giles's Gate, and comprised various galleries about 8 feet in height, from 2 to 5 feet in breadth, and occupying a total length of 4,600 feet. It is believed 'that the object of this particular working was to extract the flints which were used in great quantity in the construction of the ancient buildings and walls of Norwich.'† Similar galleries for the extraction of Chalk have been made in old times at Chislehurst, and there also are vertical shafts, some of

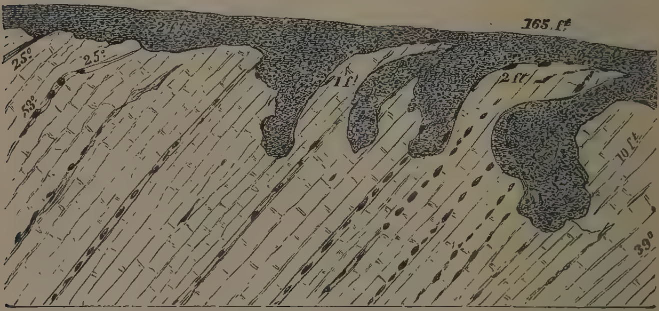

FIG. 33.—SECTION NEAR KNIGHTON MILL, MERSLEY DOWN, EAST OF NEWPORT, ISLE OF WIGHT. (A. Tylor.*)

The section shows highly-inclined Chalk with bands of nodular flint overlain by gravel. By dissolution of the Chalk an irregular piped surface with beaklike projections has been produced on a previously eroded surface of the Chalk.

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* *Quart. Journ. Geol. Soc.*, 1869, vol. xxv., p. 97.

† H. B. Woodward, 'Geology of Norwich,' *Mem. Geol. Survey*, 1881, p. 29.

which were probably dene-holes, others ordinary wells. (See p. 165.) Other pits near Brandon, Norwich, and elsewhere were opened to obtain material for gun-flints, or, in earlier times, for flint implements.

Reference has previously been made to the pipes or cavities of small and large dimensions that occur over the surface of Chalk areas, and have been produced by dissolution of the limestone. (See Fig. 33.)

Erosion of this character (as noted, p. 64) is liable to produce subsidences of ground; hence, foundations for buildings should be well tested.

The Chalk, as a rule, affords dry, healthy building-sites, except in low-lying situations. Croydon, Purley, Sutton, Guildford, and Rickmansworth may be mentioned among the localities within easy reach of London.

Upper Greensand.

This is mostly a sandy and cherty formation, varying much in character. It is intimately associated with the Gault, and the two practically form one formation, to which the name Selbornian was applied by Mr. A. J. Jukes-Browne. In East Kent, at Folkestone, the whole formation is practically clay (Gault). So also in North Buckinghamshire, and beyond; in Devon the formation is almost wholly sandy and cherty (Upper Greensand). It is convenient, however, to have the two main lithological divisions for practical purposes, especially in the intermediate areas.

Along the borders of the Weald below the North and South Downs, west of Burham, in Kent, the Upper Greensand is represented by calcareous sandstones, the upper soft and fine-grained beds being used for hearthstone; while the lower beds yield firestone and building-stone, worked extensively in old times at Godstone, Merstham, and Betchworth. The deserted underground workings at Godstone are now utilized for the growth of mushrooms.

At Farnham the upper beds of the Greensand contain some phosphatic matter, perhaps derived from layers at the base of the Chalk. (See p. 259.) There and westwards, in Hampshire, the harder beds are known as 'malmstone'; some utilized for firestone, as Gilbert White recorded; and others, known as 'white malm,' for hearthstone. The soil contains much soluble silica, and is light, friable, and fertile.

In Dorset and Devon the higher beds consist of a few layers of calcareous grit or sandstone, resting on a mass of chert-beds, sands, and sandstones, with layers and nodules of chert; below there is a series of grey, green, yellow, and white sands, that often weather to a reddish-brown sand or 'fox-mould,' and basement portions of the sands locally contain concretions of hard, calcareous sandstone known as 'cowstones.' Much of the soil contains chert stones; the sands are siliceous, and even the fossils are silicified. Tracts of heath and furze characterize the uplands and prominent outlying hills; some of them, however, are well wooded; but the ground is comparatively sterile when compared with the rich adjacent tracts of calcareous sand at the base of the Inferior Oolite and in the upper part of the Middle Lias.

In Wiltshire, as at Warminster and Devizes, thick beds of greenish-grey sand and loamy sand, with also beds of chert and sandstone occur. They fringe the Marlborough Downs on the north, and extend over the Vale of Pewsey and along the borders of the Vale of Wardour. For the most part the soil is a rich, sandy loam, good for barley; while on the scarps the larch grows well, also oak and spruce in some localities.

Many fine elevated sites for residences are to be found, as in the neighbourhoods of Devizes, Shaftesbury, Lyme

Regis, Sidmouth, the Blackdown and the Haldon Hills. All localities, except those in low-lying situations, are likely to afford good sites for residences.

Scythe-stones have been largely manufactured at Broadhembury, in Devon, from the siliceous concretions in the Upper Greensand of the Blackdown Hills; and it is considered that some of the excavations known as the 'Pen-pits,' near Penzlewood, not far from Stourton, on the borders of Wilts, Somerset, and Dorset, may have been made to get material for scythe-stones, though some may be foundations of ancient pit-dwellings.

Gault.

This is one of the more important clay-formations, and it extends along a belt of low-lying pasture and meadow-land, between the outcrops of Upper and Lower Greensand, where these formations are developed. It, however, overlaps or oversteps the Lower Greensand in its westward extent, resting in some places on Kimeridge or Oxford Clay, Lias, and even Keuper Marl, as well as other formations. In East Kent, as mentioned, it expands so as to replace the Upper Greensand, while in the West of England it occurs in an attenuated condition below that formation at Lyme Regis and near Honiton, and does not extend much farther in that direction.

In Norfolk it passes into the Red Chalk or Hunstanton Red Rock, a ferruginous limestone, about 4 feet thick; and equivalent beds occur in Lincolnshire and Yorkshire. The term Gault (Galt or Golt), is locally given on the borders of the Fenland to any stiff clay; hence, no doubt, the name came to be applied to the Gault formation, which is well developed in Cambridgeshire.

The Gault is in many areas a cold, intractable dark grey, and sometimes yellow, clay, and has even been spoken of as 'unfathomable muck'; elsewhere it gives rise to a heavy loamy soil; in some parts, however, it is highly calcareous, and the soil is marly. Phosphatic nodules occur in many localities. As in the case of other thick clays that occupy vales, the ground is not to be recommended in general for residential purposes.

Where the soil is a stiff dark clay, the ground is sometimes known as 'black land.' The village of Blackland, south-east of Calne, is on Gault, which extends north-eastwards into the Vale of White Horse. Where well-drained, the soil in general forms good pasture-land. Oaks grow well, also larch.

In the Vale of Aylesbury, which is formed in part of Gault, and in parts of Kimeridge Clay and Boulder Clay, the soil is greatly improved by downwashes of lighter material from bordering and isolated hills of Portland Beds, and other formations. On the clayey tracts of the vale ponds are readily formed for the ducks that flourish in the district.

Lower Greensand.

This formation, which is essentially a sandy series in south-eastern England, undergoes considerable changes in its exposures here and there, westwards to Wiltshire, and northwards to Lincolnshire and Yorkshire.

In the Wealden area the following subdivisions have been determined (see Figs. 34, 35):

Folkestone Beds.
Sandgate Beds.
Hythe Beds.
Atherfield Clay.

The *Folkestone Beds* consist mainly of white and brown sands, with occasionally green sandstone or grit, as at Ightham, and in places brown ferruginous sandstone or

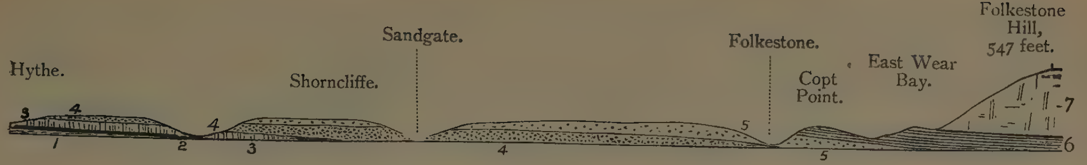

FIG. 34.—SECTION ALONG THE CLIFFS FROM HYTHE TO FOLKESTONE. (W. Topley.)
(Scale an inch to a mile.)

2, Atherfield Clay.
1, Weald Clay.
4, Sandgate Beds.
3, Hythe Beds.
6, Gault.
5, Folkestone Beds.
7, Chalk, with traces of Upper Greensand at base.

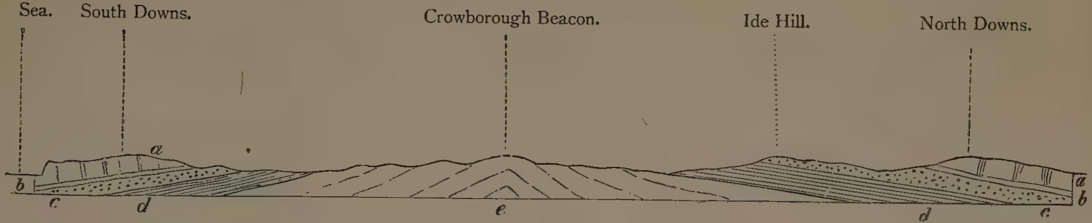

FIG. 35.—SECTION ACROSS THE WEALDEN DISTRICT.

d, Weald Clay.
e, Hastings Beds; and Purbeck Beds (exposed at surface near Battle).
a, Chalk.
b, Upper Greensand and Gault.
c, Lower Greensand.

carstone. The strata are 70 to 100 feet thick, and are somewhat calcareous in their extent from Folkestone to Ashford.

The white quartz-sands have been extensively dug for glass-making at Reigate, Godstone, Aylesford, Berstead, and near Hollingbourn; they have been used in some places for potting purposes. In general the Folkestone Beds form an infertile sandy tract, including, however, much picturesque heath-land.

The *Sandgate Beds* form a variable clayey and sandy series, that ranges up to 100 feet in thickness. They consist of dark green clayey sands and dark clays, with beds of economic fuller's earth at Nutfield, with fine sands and sand-rock obtained for moulding-sand near Pulborough, and with iron-sand at Selham, east of Midhurst, that has an average percentage of 23 per cent. of metal, as noted by Mr. G. W. Lamplugh. The soil is stiff and loamy in places, and springs are thrown out by the strata; but elsewhere the soil is lighter, and sometimes highly ferruginous.

The Sandgate Beds are impersistent, and are not shown on the Geological Survey maps in western Surrey and in some other tracts. It has, however, been considered that they may be to some extent represented in age by the Bargate Stone, a calcareous and pebbly sandstone or grit, largely quarried for building-stone near Godalming.

The *Hythe Beds* consist of sands, ferruginous sandstones, clays, chert, and limestone, the whole varying in thickness from about 60 to 300 feet. An important local subdivision is the Kentish Rag, a more or less siliceous limestone, passing west of Maidstone into cherty beds. At Maidstone the layers of rag alternate with calcareous sand or soft sandstone, known as 'hassock' or 'calkstone'; the strata are much piped and fissured, and many of the cavities and wide joints are filled with brickearth or loam.

The soil in general is stony and sandy, and it is ameliorated and rendered more fertile near Maidstone by the admixture of loam with the decomposed rag and hassock. On the more sandy and cherty tracts the soil is comparatively barren, as in West Surrey, where it is characterized by the heath-lands and pine-woods of Leith Hill, Hindhead, etc. Eastwards the ground includes the picturesque wooded tracts of Limpsfield, Sevenoaks, etc. Some beds of Kentish Rag are suitable for lime-burning; but the ragstone is used chiefly for building-purposes and road-metal.

The *Atherfield Clay*, though sandy in places, is mostly a grey and brown clay, with occasional phosphatic nodules and calcareous shelly bands. It is from 20 to 60 feet thick, and rests on the Weald Clay, with which, from an agricultural point of view, it is united.

Taken as a whole, the Lower Greensand around the borders of the Weald in Kent, Surrey, Hampshire, and Sussex, forms an elevated tract, with fine escarpments overlooking the vale of Weald Clay. Heaths, commons, and moors prevail, and there is but little pasture-land. There are plenty of good residential sites, as at Haslemere and onwards to Reigate, eastwards to West Malling, etc., and from Petersfield on the west to Midhurst, Petworth, Fittleworth, Storrington, Hassocks, etc.

In the Isle of Wight the Lower Greensand comprises in downward sequence; Carstone, 12 feet; Sand-rock, 186 feet; Ferruginous sands, 500 feet; and Atherfield Clay, 800 feet. The beds are well seen at Sandown, Shanklin, Chale, and Blackgang Chine.

In Dorset, to the south of the Chalk downs of the Isle of Purbeck, the formation is represented by about 70 feet of Atherfield Clay and 150 feet of overlying variegated sands; but the outcrop is a narrow belt, owing to the high inclination of the strata.

In Wiltshire, at Bromham, Rowde, and Poulshot, between Devizes and Melksham, the formation consists largely of ferruginous sands, 25 to 30 feet thick, and it includes beds worked for iron-ore at Seend, and quartzose sandstone, used in old times for making querns. Much of the soil is a reddish-brown ferruginous sandy loam.

In Berkshire, at Little Coxwell, south of Faringdon, the formation in its lower part comprises sponge-gravels, false-bedded quartzose conglomerate and sand, with many sponges and other fossils. In the upper part there are clays and sands with bands of ironstone, the united thickness amounting to from 70 to 100 feet.

Coarse ferruginous and pebbly sands, representing the Lower Greensand, and about 50 feet thick in places, occur on Boar's and Hurst Hills, south-west of Oxford, and farther south at Culham. In Buckinghamshire the formation comprises white sands used for glass-making at Hartwell and Stone, near Aylesbury; also beds with phosphatic nodules at Brickhill, and fuller's earth at Wavendon.

In Bedfordshire, the Woburn sands, 30 to 220 feet thick, constitute the Lower Greensand, but they include beds of economic fuller's earth, bluish and greenish in colour, that are worked by means of shafts or 'earth-wells.'

At Leighton Buzzard there are extensive sand-pits, from which are obtained glass-sand, sand for filter-beds, for mortar, silver sand, for potting, etc. There are also good tracts of land for market-gardening. (See p. 149). Phosphatic nodules were formerly worked at Potton, and also at Wicken and Upware in Cambridgeshire.

The uplands of Lower Greensand in Bedfordshire contain good residential sites near Woburn, Aspley Guise, Ampthill, etc.

The Lower Greensand of Cambridgeshire is about

70 feet thick, and consists of false-bedded yellow and brown sands, with ironstone concretions, and layers of loam. It occurs at Ely, Haddenham, etc.

In Norfolk the Lower Greensand comprises in the upper part the carstone, a hard, brown sandstone with small quartz and lydite pebbles, about 40 feet thick in places, and well seen on the coast at Hunstanton, beneath the Red Chalk. The rock is softer inland, and is quarried at Snettisham for building-purposes, blocks being shaped by an axe, and hardening on exposure. From its colour it is locally known as 'ginger-bread stone.' Beneath the carstone there are beds of clay with septaria, locally 30 feet thick, but impersistent; they have been grouped as the Snettisham Beds, as in that locality, and also at Dersingham and Heacham, they are worked for brick-making. The lower part of the formation, known as the Sandringham Beds, consists of light-coloured sands and flaggy sandstone that attain a thickness of 100 feet. Much of the soil is a deep, sandy loam, 2 to 4 feet thick, overlying sand or rubble of carstone, and it is sometimes crimson or purplish in colour. It gives rise to heathy commons and warrens, including Sandringham Warren.

In Lincolnshire there occur a variable series of beds, all at one time grouped as Lower Greensand, as follows:

	Feet.
Carstone, coarse ferruginous clayey grit ...	8 to 40
Tealby Beds, limestone and clay	10 to 220
Claxby and Hundleby iron-ore	up to 14
Spilsby Sandstone, brown and white sands with masses of hard calcareous grit	10 to 50

It is considered not unlikely that the Spilsby Sandstone may represent beds of Upper Jurassic age (Purbeck), so that the higher strata may possibly be of Wealden age in part, as well as Lower Greensand.

In Yorkshire the strata are represented by the Speeton Clay.

Wealden.

This lower portion of the Cretaceous system comprises two main divisions in the Wealden area, with sundry subdivisions, as follows:

- Weald Clay.
- Hastings Beds
  - Upper Tunbridge Wells Sand.
  - Grinstead Clay.
  - Lower Tunbridge Wells Sand.
  - Wadhurst Clay.
  - Ashdown Sand.

The Hastings Beds have been a good deal disturbed and faulted, so that the regular succession of the subdivisions is interfered with in many places, causing more rapid changes in the soils and substrata. Lignite has been found in most of the strata, and has given rise to some fruitless trials for coal. (See Fig. 35, p. 265.)

Weald Clay.

This is on the whole a great clay formation, about 1,000 feet in thickness; but it includes in the upper part layers and beds of sand, as near Chiddingfold, also bands of shell-limestone, known as Sussex, Petworth, and Bethersden Marble, the last-named locality being north-east of Tenterden. In the lower part there are included beds of sand and sandstone, known as Horsham Stone. Where this rock is exposed the land is light, but apt to be rather wet at times, as noted by Topley, probably on account of the fine character of the sand. The Horsham Stone and the Marble Beds are used for paving pathways in the wetter tracts of the clay district.

Over a great part of the Weald Clay the soil is pale, yellowish, or whitish, stiff and unctuous, but sometimes browner on the lower slopes. It is largely under permanent grass or wood-land, with fine oaks, etc. Beans, wheat, oats, and clover are, however, cultivated in places, as well as hops. (See p. 150.)

In the upper part of the clay area in Sussex, as noted by Mr. G. W. Lamplugh, the intercalated sandy layers and the 'creep' of the clay downhill give rise to an arable loam.

Hastings Beds.

The uppermost divisions of this series, the *Upper and Lower Tunbridge Wells Sands*, consist largely of very fine sands—so fine, indeed, and closely packed that, as remarked by Topley, the ground is often wet and rushy, as water does not readily percolate after heavy rain. Indeed, on hill-sides during rain, as near East Grinstead, the water may be seen coursing downhill over grassy slopes. The sandstones pass from sand-rock, which easily crumbles, into harder stone, much fissured, and worked for building-purposes. Layers of white and yellow loam also occur in the series.

Coarser sands and sandstones occur, as at Tunbridge Wells. In that neighbourhood the High Rocks, Toad Rock, and other indurated and weathered masses of sandstone, stand out boldly at the surface.

Clays and shales occur in the sandy strata, the *Grinstead Clay*, 10 to 50 feet thick, being of sufficient importance to be shown on the Geological Survey map. In the upper beds there is also a local band known as the *Cuckfield Clay*, 15 feet thick.

The Upper Tunbridge Wells Sand ranges in thickness up to about 200 feet, and the lower division from 60 to 100 feet. Good residential sites are to be found in most areas on this group of strata, as at Horsham, East Grinstead, Tunbridge Wells, Cranbrook, Balcombe, Hay-ward's Heath, and Cuckfield, also at St. Leonard's and the old village of Bexhill.

The *Wadhurst Clay* consists of shale or clay with occasional layers of calcareous sandstone, and it yields a yellowish or brownish loamy soil. Sometimes, however, the upper surface of the clay is bright red, as near Tenterden. The division is from 120 to 250 feet thick. The thin ironstone bands, which occur near the base, were worked by the Romans, if not earlier, in Sussex and Kent, and in two or three localities in Surrey. These beds subsequently furnished iron-ore to the old workings of the Weald until the last furnace at Ashburnham was extinguished in 1828.

The *Ashdown Sands*, though essentially sandy, form a very mixed and variable series of sands, sand-rock, sandstone, white, blue, and coloured clays (known as 'cat's brains'), with lignite. Near Hastings the lower beds of mottled clay have been termed the 'Fairlight Clays.' The total thickness amounts to 400 or 500 feet. Very mixed sandy, loamy, and clayey soils occur throughout the area.

On Ashdown Forest the soil is reckoned to be rather poor; but there are fine sites for residences about Crowborough (see Fig. 35, p. 265), Heathfield, Battle, Hastings, and the newer town of Bexhill.

Wealden Beds, consisting of white and yellow sands and sandstones, red, grey, and purple mottled clays, with fine quartzose conglomerate and lignite, occur in the Isle of Wight, at Brightstone (Brixton), Brook, and over a small area north of Sandown.

A fine series of similar strata is exposed along the cliffs of Swanage Bay, in Dorset, the estimated thickness being 2,350 feet. Inland they form much heathy ground.

In Oxfordshire the Shotover Sands on Shotover Hill, at Great Milton and Great Haseley, and also at Brill in Buckinghamshire, largely consist of more or less ferruginous sands, with white and grey sands, loams, and clays. Exceedingly fine-grained sand on Shotover Hill has been utilized in the manufacture of scouring-soap. Elsewhere we find iron-sands and ironstone with casts of shells, also ochre, which was worked at Shotover. There beds of white clay were formerly used in the manufacture of tobacco-pipes, and fuller's earth also occurs in one or two localities. The beds, as might be expected, yield a variety of soils.

CHAPTER XXI

GEOLOGICAL FORMATIONS (*Continued*).

JURASSIC

THIS system is divided as follows:

Upper Oolitic	Purbeck Beds. Portland Beds. Kimeridge Clay.
Middle Oolitic	Corallian. Oxford Clay, with Kellaways Beds.

	South-West England.	*Midland Counties.*	*Yorkshire.*
Lower Oolitic	Cornbrash.	Cornbrash.	Cornbrash.
	Forest Marble, with Bradford Clay.	Great Oolite Clay.	Upper Estuarine Series (in part equivalent to Great Oolite, in part to Inferior Oolite).
	Great Oolite, with Stonesfield Slate.	Great Oolite Limestone.	
	Fuller's Earth (Fullonian).	Upper Estuarine Series.	
	Inferior Oolite.	Lincolnshire Limestone, with Collyweston Slate.	Grey, or Scarborough Limestone Series.
			Middle Estuarine Series.
			Millepore Bed.
	Midford Beds.	Northampton Beds, with Lower Estuarine Series and Northampton Sand.	Lower Estuarine Series.
			Dogger.
			Blea Wyke Beds.

Liassic	Upper Lias. Middle Lias. Lower Lias.

In the South-West of England, from Dorset to the northern Cotteswold Hills, and from Chipping Norton to Banbury and Edge Hill, the strata are practically free from coverings of Glacial Drift; whereas from Brackley, Buckingham and Aylesbury, through Northamptonshire to Lincolnshire, and again in Yorkshire, there is much Boulder Clay and gravel and sand that alter the character of the land wherever they occur.

The Oolites comprise a great series of sands, sandstones, and limestones, alternating with thick formations of clay and shale; and in the South-West and West of England they form a succession of Stonebrash hills and Clay vales. The subdivisions, however, undergo changes as the Oolites are traced from the Dorset coast through Oxfordshire into the Midland Counties, and again through Lincolnshire into Yorkshire, so that, in the case of the Lower Oolites especially, different subdivisions have to be made in South-West England, the Midland Counties, and Yorkshire.

Many of the limestones are characterized by granules like the roe of a fish, hence the name Oolite. The clays contain occasional bands of limestone, and more often layers of cement-stone or septaria. These are nodular masses of argillaceous limestone, the cracks in which are filled with calc-spar forming the septa. The limestones, like the Chalk, are subject to surface dissolution, and are piped in many places.

Oolitic Series.

Purbeck Beds.

These strata in the South of England rest conformably upon the Portland Beds, and pass gradually upwards into the Wealden. They are best developed in Dorset in the so-called Isle of Purbeck, and the lower and part of the middle division occur on Portland. They extend over portions of the Vale of Wardour above Tisbury, and are to be seen in small outlying tracts at Swindon, Garsington, Long Crendon, Brill, and Aylesbury, and in inlying tracts near Battle in Sussex.

In Dorset the formation varies in thickness from about 176 feet at Lulworth to nearly 400 feet at Durlston Bay, Swanage. There the strata consist of the following subdivisions:

		Feet.
Upper Purbeck	Grey, blue, green, red, and purple marls; clays and shales, occasional sands, and bands of shell-limestone, known as Purbeck Marble	60
Middle Purbeck	Dark shales and hard shelly limestones, Swanage building-stone; also an oyster bed known as the Cinder Bed	166
Lower Purbeck	Grey and buff marls, shales, and hard limestones, including beds with stools and trunks of trees, Dirt Beds	170

Beef, or fibrous carbonate of lime, selenite, alum, and nodules of chert, are found at various horizons; gypsum occurs in the lower beds. In addition to marble, building and curb stone, some layers (in the Lower Purbeck), yield material for hearthstone and holystone.

In the Lower Purbeck Beds there are one or two earthy layers known as 'Dirt Beds'; but one band in particular, known as the 'Great Dirt Bed,' is conspicuously developed on Portland and to the east of Lulworth Cove. It is an irregular layer of clay and carbonaceous earth about 1 foot thick in places, with partially rounded stones derived from the underlying Portland limestone, and from some of the hard Purbeck limestones known as 'caps.' On top of the Dirt Bed, and forming practically the upper part of it, is an irregular band of calcareo-siliceous masses, circular or oval in form, 9 inches to 1 foot or more in thickness, in which remains of silicified tree-stumps and trunks of conifers and cycads occur. Some of the Lower Purbeck Beds, as may be seen at Durlston Head, and many other places, are much shattered, a feature due mainly to the tilting, faulting, and thrusting, which have affected the strata in proximity to the hard Portland Beds. The irregular Dirt Bed was no doubt a plane of weakness, and the features in the broken beds have been modified to some extent by dissolution of calcareous matter.

At the base of the Middle Purbeck Beds there is also a Dirt Bed, a dark grey and brown carbonaceous shale about 1 foot thick, from which mammalian and other remains have been obtained at Durlston Bay. About 10 feet higher is another layer of black carbonaceous shale.

In the Isle of Purbeck the soil is a brown and somewhat brashy clay, from 1 foot to 18 inches deep, much of it heavy and requiring to be drained. A good deal of the land is in pasture; elsewhere crops of wheat, beans, potatoes, and peas, are grown. Some hedgerows, but mostly stone walls, divide the fields. The Lower Purbeck Beds have the larger tracts under arable cultivation. Along the Middle Purbeck outcrop the ground is much broken owing to old stone-workings, and the land is in pasture. There are few trees, owing to the exposed situation; but near Durlston Head there are fir plantations, and the gorse grows near the edge of the cliffs where the land is naturally drained.

In the Vale of Wardour the Purbeck Beds attain a thickness of about 85 feet, and consist in the lower part mainly of limestones with clays and shales, some of the limestones being quarried. The middle and upper beds comprise softer strata of marls, sandy limestones, which weather into loose sands, and clays with many shelly layers. The area is almost wholly under grass and tillage, but some of the clayey lands are cold and poor.

The small outlying tracts that occur at Swindon, in Oxfordshire and Buckinghamshire, do not greatly affect the agricultural character of the land. At Swindon the strata rest on an eroded surface of the Portland Beds, and comprise about 30 feet of greenish clay, marls, sandy limestone, and hard fissile white limestone. In the outliers to the north, the Purbeck Beds comprise from 4 to 7 feet of marls and soft limestone (Malm), clays, sands, sandstone, and fissile limestone (Pendle).

To the north and north-west of Battle the strata were proved to a thickness of about 400 feet in the sub-Wealden boring, and they comprise grey and blue limestones, hard calcareous sandstones, and shales, with gypsum in the lower part. They include strata formerly grouped as Ashburnham Beds. Hops have been grown at Pounceford.

Portland Beds.

This formation consists of earthy, chalky, and oolitic limestones, chert-beds, sands, sandstones, marls, and clays, and includes the famous freestones of Portland, and some of the most durable of our oolitic limestones.

At Upway, near Weymouth, in the higher part of the formation, there are beds of chalky limestone, with black and white flint or chert, so like the Chalk formation that, until fossils are obtained, the visitor might conclude that he was in a chalk-pit.

The Portland Beds are most prominently developed in the Isle of Portland, and along tracts of South Dorset, from Portesham and Upway to Durlston Head. They are quarried for building-stone and lime-burning.

At Portland the general succession is as follows:

		Feet.
Upper Portland Beds	Roach, cavernous limestones, with casts and moulds of shells ...	up to 9
	Freestone Beds: good stone, oolitic limestone, mainly in upper part	30 to 40
	Chert Beds: limestones with bands and nodules of chert	60 to 75
Lower Portland Beds	Sands and marls, with bands and nodules of earthy and sandy limestone	120 to 170

Portland Isle is bleak and bare, owing to the almost entire absence of trees, except at Fortune's Well and Pennsylvania Castle. The southern portions of the land are under cultivation.

In the district of Purbeck the outcrop is nowhere very broad; the coast is marked by rugged cliffs, and by bold and fairly smooth escarpments with steep slopes, mainly of the Lower Portland brown and greyish-green sands, with bands of calcareous sandstone that crop out here and there on the slopes. Where the Kimeridge Clay occurs at the base of the declivities, springs issue at the junction. The crests of the scarps, high rounded hills, are usually formed of the chert-beds and limestones, and the upland areas are in places under cultivation for corn, the fields being divided by stone fences. The slopes are almost wholly grass-covered; fine lynchets may be observed in places, while some of the steeper slopes form sheep-walks with little narrow and interlacing terraces. (See pp. 175, 220.)

Encombe Valley, or the 'Golden Bowl,' with its wooded and verdant slopes, appears rich and picturesque when contrasted with the somewhat bare and bleak outcrops of Purbeck Beds along the higher ground.

The elder and teazel grow abundantly on the débris that covers the slopes of Kimeridge Clay.

In the Vale of Wardour the Upper Portland Beds comprise some excellent, if variable, building-stones: buff and greenish, sandy, oolitic, and glauconitic limestones, the series being altogether 50 to 60 feet thick in places. The Lower Portland Beds consist of sandy and clayey beds about 38 feet thick. The clay-bands (not distinguished on geological maps) throw out water.

The soil on the stone-beds is a rubbly or brashy marl and loam, under grass, or in arable cultivation for corn and roots. There are few trees on the uplands, but the slopes are wooded in places. (See p. 38, and Plate IV.)

Portland Beds occur beneath the outlying masses of Purbeck Beds already noted. The Upper division is largely quarried at Swindon, where it comprises chalky beds, sands, and hard sandstone (Swindon Stone), and fossiliferous limestone, with lydite pebbles. The Lower Portland Beds consist of clay 14 to 20 feet, and sands with doggers, about 40 feet.

At Shotover Hill, east of Oxford, the upper beds include, in downward succession, sands, whitish limestones, clays, loam, and sands, rubbly glauconitic limestone and clay, with lydites and phosphatic nodules; beneath are yellow and greenish sands, with huge doggers or 'sand-ballers' of calciferous sandstone, that are broken up for road-metal. The series is about 100 feet thick.

Thence various small tracts are to be seen at Great Milton, Long Crendon, Thame, Brill, and Aylesbury, where in places there occur greenish marl, chalky limestone, hard calcareous sandstone, decomposing into soft sand, and grey and greenish (glauconitic) sandy and oolitic limestone (burnt for lime). The lower beds are not much exposed, but at Brill and Aylesbury, beneath the stone-beds, there is about 20 or 25 feet of blue loamy clay (well adapted for brick-making), known as the Hartwell Clay, from Hartwell, south-west of Aylesbury. This clay merges downwards into the Kimeridge Clay.

The soil varies, but much of it is a sandy and fertile loam, under arable cultivation.

Kimeridge Clay.

This great clay formation is well exposed along the dark cliffs of Kimeridge, where the total thickness amounts to 900 feet or more; a still greater thickness, about 1,300 feet, appears to occur below ground in the Wealden area, near Battle, as indicated by the sub-Wealden boring.

The Kimeridge Clay consists of dark bluish-grey, more or less bituminous, shales and paper-shales, iron-stained in places, with prominent bands and nodules of cement-stone, which form ledges on the coast. Phosphatic nodules occur in some localities, and there is much selenite in places, as at Shotover Hill, near Oxford. The fossils are usually much flattened, and some of the mollusca, such as *Lucina*, are very conspicuous on some of the surfaces of the black shales, with their small, white, oval shells.

Bordering Kimeridge Bay the hilly land is mostly under meadow and pasture, and on the western side, on top of the cliff, there is a rabbit-warren in the dry, shaly soil. In the deep valleys near Encombe there is much limestone rubble derived from the Portland Beds.

Throughout its extent inland the area is flat and gently undulating, mostly under grass, with good hedgerows, and many dairy farms, as in Wiltshire and Dorset (Vale of Shaftesbury); but there are also tracts under arable cultivation for wheat, beans, and potatoes.

The soil in general is a dark brown and tenacious clay, requiring to be well drained, and improved by lime-manure; but it is regarded in general as more fertile than that on the Oxford Clay. The soil is modified in some areas, as in the Vales of Aylesbury and White Horse (both partly on Gault Clay) by downwashes from bordering strata, whereby a rich loam extends over the surface.

In Lincolnshire the Kimeridge Clay is covered in places by tracts of infertile Drift sand; but the ground has been improved by dressings of the clay.

In the Vale of Pickering there is good meadow and pasture-land on the Kimeridge Clay.

T. Davis, in 1813, referred to 'the deep oak-tree loams about Mere, Knoyle, Sedgehill, and Semley';* and it was through him that the formation was termed the 'Oak Tree Clay' by William Smith in 1816. In those days, however, the sequence of geological formations was but partially established, and the term was not confined to the strata now known as Kimeridge Clay.

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* 'Agriculture of Wiltshire,' p. 113.

Kimeridge is noted for the occurrence of the so-called Kimeridge Coal or Black Stone, which has locally been used as fuel, and has been burnt at some of the potteries near Poole. Much of the shale is more or less bituminous, but the Black Stone is especially rich, and from it naphtha has been distilled, and tar, disinfectants, and other products have been prepared.

Corallian.

This is a variable group of sands, sandstones, and calcareous grits, oolitic and shelly limestones, coral-beds, ironstone, and clays; and different subdivisions become necessary when the strata are traced across England from Dorset to Yorkshire.

In the neighbourhood of Weymouth the following divisions were established by W. H. Hudleston and J. F. Blake:

		Feet.
Upper Corallian	Upper Coral Rag and Abbotsbury Iron-ore Sandsfoot Grits	15 to 25
	Sandsfoot Clay	12 to 40
	Trigonia Beds (ferruginous oolitic limestones)	12 to 16
	Osmington Oolite	45 to 60
Lower Corallian	Bencliff Grits (sands with doggers of calciferous sandstone)	10 to 35
	Nothe Clay	30 to 40
	Nothe Grits	20 to 35

We have thus a series of strata calculated to give rise to a diversity of soils. Most prominent are the ruddy soils of good depth on the ironstone-beds of Abbotsbury, where potatoes are much cultivated. The district is somewhat devoid of trees, except in sheltered places, and the fields are divided by stone walls and hedgerows. Much of the soil may be described as a brown, sandy, and friable loam, more or less brashy in places. Freestones are quarried at Marnhull and Todbere in North Dorset.

In Dorset there is no very definite plane of division between the Oxford Clay and Corallian, nor between Corallian and Kimeridge Clay. They are connected by alternations of clays with stone-beds.

Elsewhere generally there is a passage between the Oxford Clay and the Lower Calcareous grits and sands; but in Wiltshire and Oxfordshire the change from the Corallian limestones to Kimeridge Clay is mostly abrupt.

In this South-Midland area the broad general divisions are as follows:

Upper Corallian	Limestones and coral beds, with oolitic freestones, and occasional sandy and clayey beds in upper part, as at Highworth.
Lower Corallian	Sandstones and sands (Lower Calcareous Grit).

Iron-ore, like that of Abbotsbury, occurs at the top of the Corallian at Westbury in Wiltshire, where it is extensively worked.

The direct derivation of the soil from the substrata is exemplified near Steeple Ashton, where, about a mile south-east of the village, numerous fossil corals have been gathered from the ploughed fields.

Generally speaking, in the Corallian areas we find an admixture of meadow, pasture, and ploughed lands, of hedgerows and stone walls, and as a rule many good sites for residences.

As we pass beyond Wheatley, in Oxfordshire, to Quainton and Stewkley, the Corallian beds are represented mainly by clay, known as the *Ampthill Clay*, which, with some intercalated and associated bands of rock, extends to Cambridgeshire. Near Arngrove Farm, not far from Studley, in Oxfordshire, the Lower Corallian contains a bed of cherty rock, 4 or 5 feet thick, termed the 'Arngrove stone' by Dr. A. Morley Davies.

The Ampthill Clay is about 60 feet thick at Ampthill. It has been well exposed in brickyards near Gamlingay, where red and white bricks are made, and bands of limestone are burnt for lime. Much of the clay is dark grey or black, and it contains small crystals of selenite. At its base occur the Elsworth Rock, and the Red Rock of St. Ives in Huntingdonshire. At Upware, on the borders of the Cam, six miles south of Ely, there is a local development of oolitic and shelly limestone, but no more prominent stone-beds are seen until Yorkshire is reached. The Ampthill Clay represents the Corallian through the Fenland area and Lincolnshire, forming with the underlying Oxford Clay and overlying Kimeridge Clay the great Fen Clay formation.

In Yorkshire the following subdivisions have been made in the Corallian formation, but several of them are only locally developed:*

	Feet.
Upper Calcareous Grit	30 to 45
Upper Limestone	40 to 50
Middle Calcareous Grit	16 to 80
Lower Limestone	20 to 60
Passage Beds: siliceous limestones (Greystone) passing into sandstones and grits	25 to 40
Lower Calcareous Grit	up to 160

The Tabular Hills to the north of the Vale of Pickering, and the Hambleton Hills on the west, overlooking the Vale of Mowbray, are formed of Corallian rocks; while to the south come the Howardian Hills formed of Corallian, Oxfordian, and also Estuarine Beds of the Lower Oolites. These strata, varied as they are, yield different types of soil, that on the grits being sandy, infertile, and forming moor-lands and rabbit-warrens; while the calcareous beds yield good and productive soil that is cultivated, and supports the best upland grass. As remarked by Mr. Fox Strangways, 'the influence of the underlying rock upon the soil and vegetation is very marked in some places,' by grass-land along the calcareous belts and heather on the sandy tracts. (See p. 26.) Some parts are too steep for arable cultivation, and remain as moor-land, or are utilized for plantations.

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* C. Fox Strangways, 'Jurassic Rocks of Britain,' vol. i., *Mem. Geol. Survey*, 1892, Plate VI.

Oxford Clay.

This is one of the great clay-formations, exposed in a series of vales from Weymouth in Dorset, through the Vale of Blackmore to Oxfordshire, the Vale of Bedford, and Lincolnshire to Yorkshire. It occurs also near Uig and other parts of Skye.

In mass it is from 300 to 500 feet thick, and consists of grey, bluish, and greenish-grey clay, called 'Clunch Clay by William Smith; and dark grey, sometimes purplish, laminated shale in the lower part; but, on the whole, it is much less shaly than the Kimeridge Clay.

At the base there is usually a series of loams and sands with beds of calcareous sandstone, known as the *Kellaways Beds*, from Kellaways, north-east of Chippenham. Sometimes the sandstone appears in huge spheroidal masses or doggers, with 10 or 12 feet of clay at the bottom, resting on the Cornbrash. The strata form a gentle escarpment, as at South Cerney (see Fig. 36), in the neighbourhood of Bedford, and elsewhere.

At Kellaways there are now but few and small exposures of the Kellaways Rock, fissile calcareous sandstone, with many fossils; the stone is much decalcified in places, and from 1 to 3 feet of brown loamy soil rests upon it.

Selenite and septaria are common in the Oxford Clay; and the larger septaria, known as 'turtle-stones,' have been cut and polished near Weymouth. Here and there the shales are markedly bituminous, as near Trowbridge. Bands of sandy limestone occur in the blue clay at St. Neot's in Huntingdonshire.

In the neighbourhood of Braydon, on part of the old Forest of Braydon in northern Wiltshire, there was land that was 'looked upon as one of the most unproductive in England.' The soil, a clayey mould, was but 4 or 5 inches thick, resting on a stiff, yellowish clay subsoil, not wholly impervious, and below was the great mass of Oxford Clay. It is not surprising that 'the soil was either like a soapy cheese or a brick-bat'; that in wet weather slush and pools of water prevailed, and in dry weather the soil was baked. The soil was found to contain a great deal of fine micaceous sand, and it was pointed out that 'fine sand and some clay runs into a closer, heavier, and certainly less productive soil than agricultural clays which are almost free from sand.' The soil, moreover, contained much iron as protoxide, it was deficient in phosphoric acid, and poor in potash and lime. The subsoil contained an appreciable quantity of phosphoric acid, and was richer in potash and lime; otherwise, while it naturally contained less organic matter, the

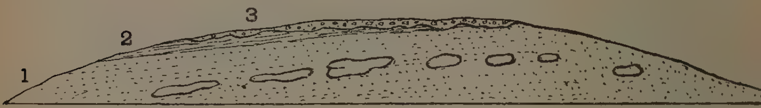

FIG. 36.—SECTION IN RAILWAY-CUTTING, SOUTH CERNEY, GLOUCESTERSHIRE.

3, Gravel, 1 to 3 feet. 2, Oxford Clay, 1 to 3 feet.
1, Sands, with some ferruginous layers and large concretionary masses or doggers of calcareous sandstone (the isolated dogger to the right has probably to some extent slipped), about 20 feet. (Kellaways Beds.)
Greatest depth, about 25 feet.

composition did not differ greatly from the soil which was in the main formed from the subsoil. Want of aeration and want of drainage were prime causes of the lack of fertility, and when these were remedied, and the land had been manured, grass of excellent quality for hay and pasture was produced.*

The natural soil on the Oxford Clay is as a rule but thin; it is a stiff, cold, and stubborn clay, yellowish or brownish, and sometimes dark grey, in colour, with a tenacious clay subsoil. A heavy loam and a lighter loamy soil are present on the better lands, the soil being improved in part by cultivation, and, in some cases, by downwashes from bordering hills of Corallian strata, as in the Vale of Blackmore.

At Melbury Osmond, in Dorset, the soil contains a good deal of flinty and cherty detritus from adjacent hills of Chalk and Upper Greensand.

In Bedfordshire, bordering the Woburn Hills, the soil is rendered fertile by downwashes from the Lower Greensand.

The land is chiefly under grass, and there are rich pastures in Wiltshire, Oxfordshire, and elsewhere, with good and well-timbered hedgerows. Wheat, beans, clover, etc., are cultivated in some areas.

In Yorkshire the Kellaways Beds, well seen at Scarborough, Hackness, and other places, consist of soft sandstones, more or less clayey and shaly, that pass into hard ferruginous red rock, in places calcareous, and sometimes containing quartz pebbles. The soil is apt to be dry, as the harder rocks are much jointed, and they form, when weathered, rounded hills known as 'nabs.' The Oxford Clay consists mainly of grey sandy shales.

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* Dr. A. Voelcker and Professor Coleman, *Journ. Roy. Agric. Soc.*, series 2, 1866, vol. ii., p. 377.

Cornbrash.

The Cornbrash, as its name implies, forms a brown, brashy, and loamy soil suitable for the growth of corn. In general it consists of somewhat pale earthy and shelly limestones, with marly partings, and is never of great thickness, varying from a foot or two near Bedford to about 25 or 30 feet. At the surface the stone-beds weather into a limestone rubble (known as 'kale' in Lincolnshire); deeper down they are bluish-grey, and the stone is used for building-purposes as well as road-metal. Fossils are often abundant in the ploughed fields, which are usually divided by hedgerows, sometimes by stone fences. There is good pasture, as well as arable, land, and the ground is almost wholly under cultivation.

In Yorkshire the Cornbrash, as described by Mr. Fox Strangways, consists of a few feet of ferruginous limestone overlain by dark shales, known as the 'Clays of the Cornbrash,' which pass into the sandy shales of the Kellaways Beds. The outcrop of the formation is so narrow as to be 'of no importance from an agricultural point of view.'

Many villages are situated on the outcrop of the Cornbrash, and good sites for residences are generally to be found.

The Cornbrash has been extensively burnt for lime, especially in olden times, and it is said to have made a better building-lime than the Forest Marble.

GREAT OOLITE SERIES, SOUTH-WEST ENGLAND.

Forest Marble.

This formation owes its name to William Smith, who applied it to the strata in the Forest of Wychwood, in Oxfordshire. From that neighbourhood, and from

Bicester, it extends to the Dorset coast near Weymouth, increasing in thickness from about 12 feet to 100 feet near Cirencester, and 130 feet near Sherborne in Dorset. To the north-east of Bicester the Forest Marble is represented by the Great Oolite Clay. (See p. 294.) It is an exceedingly variable formation, but is characterized by hard, shelly, and flaggy oolitic limestones, much current-bedded, that have locally been polished in slabs for mantelpieces. The shelly beds are largely made up of fossil oysters, which have a purplish tinge on the surfaces of the stone. As a marble the stone is poor, as it often contains ochreous galls or kernels, irregular cavities filled with ochreous clay, and also lignite. The Forest Marble includes thick beds of clay or shale, with thin films of gritty limestone; also buff sands with large concretionary masses of calcareous sandstone, more or less flaggy and fissile, as at Hinton Charterhouse, south-east of Bath, where the stone is used for road-metal (Hinton Sandstone). When these fissile sandstones, or doggers, assume a spheroidal form, they are liable to flake off in the shape known as 'pot-lids,' as near Malmesbury. Elsewhere there are thin flaggy limestones that mostly in old times, but in some places now, are used as stone tiles. At the base of the formation, at Bradford-on-Avon, there is a local subdivision known as the 'Bradford Clay,' a marly clay resting on a very fossiliferous bed. It is not persistent, but is seen at Corsham and near Cirencester, and on the Dorset coast near Langton Herring.

In its course through Dorset and South Somerset the Forest Marble rests directly on the Fuller's Earth or Fullonian formation, and usually forms a prominent scarp, grassy, scrubby, and wooded, above the clay vale, being the boldest of the local Jurassic features.

The land is mostly cultivated along the dip-slopes, where the fields are divided by stone fences and good hedgerows. There is arable land, where corn, beans, etc., are grown, and a good deal of pasture and meadow land.

The soil is subject to considerable changes, but on the whole is fairly fertile, varying from light and loamy to reddish-brown brashy clay and stiff clay.

South-west of Long Furlong, near Cirencester, the Forest Marble was decalcified in an irregular cavity 25 feet across and 5 feet deep, the soil being a reddish-brown loam.

On the more clayey tracts, and some of those where clay alternates with slabby limestones, the ground requires deep draining. The clay-land is apt to be much fissured in dry weather.

The best sites for residences are on the thicker masses of flaggy oolitic limestone.

The stone-beds have been largely used for building-purposes, and especially for stone fences and road-metal. Slabs known as 'Flat Stones' are utilized for pigsties, and some of the excavations are known as 'slate and plank quarries.' Stone tiles for roofing have been worked near Tetbury, at Poulton near Fairford, etc. Clays for brick and tile making are also obtained in many localities; and marly clays, as at Holwell in Oxfordshire, have been used for marling land.

Great Oolite.

This formation varies to a considerable extent in its course from a little south of Bradford-on-Avon, through the Midland Counties, to Lincolnshire and Yorkshire.

In the area from Bradford-on-Avon to Bath, Minchinhampton, and Burford, it consists mainly of oolitic limestones, rag-beds (shelly limestones that do not form freestones), and subordinate marls. The basement-beds comprise marls and flaggy beds that have locally been used as stone tiles.

The bolder features in the Jurassic rocks from the neighbourhood of Bath to Minchinhampton are formed by the Great or Bath Oolite. This area includes the southern portion of the Cotteswold Hills, intersected by deep valleys around Bath, with occasional scarps of bare rock, and forming a fine escarpment northwards. The elevated dip-slope that extends towards Monkton Farleigh and Wraxall, Castle Combe, Tetbury, and Cirencester, is in part covered by the shelly and oolitic limestones and clays of the Forest Marble. It forms in some parts a rather monotonous tract of fairly even and gently sloping land, partly under arable cultivation for wheat, barley, potatoes, and roots, partly under sheep-pasture, with large farms and fields divided by dry stone walls and hedgerows. On the uplands there are comparatively few trees, a few clumps here and there; but there are plantations of fir, beech, ash, etc., on the slopes. The term Oxfordshire Downs is applied to the oolitic uplands, famous for sheep, in the neighbourhood of Burford.

The soil varies from a light and brashy fertile loam and rubbly marl to a somewhat sticky brown and less brashy clay or clay-loam, that is by no means so fertile.

Fine and picturesque sites for residences occur on the borders of the escarpments, and elsewhere good, dry foundations occur on the higher grounds.

Dry valleys occur in the uplands, and there is sometimes a deficiency of water for stock. There are fine and copious springs in many places at the base of the formation, at the junction with the Fuller's Earth Clay, and near the foot of scarps. Mr. J. A. Gibbs has remarked that the cultivation of water-cress is neglected in situations such as the Coln Valley, where it might be grown.*

Good building-stone, including the famous Bath Stone, is worked at Bradford-on-Avon, Bath, Corsham, and

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* 'A Cotteswold Village,' 1898, p. 100.

Minchinhampton. Some beds are also used for road-metal and lime-burning. Good freestone has also been obtained at Taynton, near Burford, and is now worked at Milton near Shipton-under-Wychwood.

Stone tiles, or so-called slates, were formerly obtained at Sevenhampton from fissile oolitic and sandy limestones; also at Stonesfield, where they have mostly been mined, and are still obtained when required.

Fuller's Earth, or Fullonian.

This is an important division of clays, marls, and earthy limestones, which occurs in the West of England. It is present directly below the Forest Marble and above the Inferior Oolite in Dorset and South Somerset, owing to the absence of the Great Oolite; and between the Great and Inferior Oolites in the country a little south of Bradford-on-Avon, and thence northwards in the Cotteswold Hills. Eastwards it is represented to some extent by the Upper Estuarine Series.

The name was applied to the formation because beds of economic fuller's earth have long been worked at Midford, and also at Wellow, near Bath. These layers are from 1½ to 5 feet thick, blue at a depth, and yellow when weathered. The material was much used in old times for fulling at the cloth-mills at Frome in Somerset, and in those near Stroud in Gloucestershire.

The material is a slightly calcareous clay, which falls to a powder when placed in water, owing to a peculiar physical condition of the silicate of alumina, which is in a non-plastic state.

Economic fuller's earth has also been observed at Notgrove, south-east of Cheltenham.

The clays in the formation are of considerable thickness. They are grey and bluish-grey, and, being more or less calcareous, they pass into marls. Occasional seams of fibrous carbonate of lime, or 'beef,' and nodules of 'race' occur. The beds are worked for brick-making.

Bands of pale grey and brown argillaceous limestone are developed towards the central portion of the series. They constitute a band termed the Fuller's Earth Rock, which, as at Milborne Port and near Shepton Montague, forms a noticeable escarpment. The stone has been burnt for lime, and used for building walls and mending by-roads, but it is by no means a very durable material. The best residential sites would be found on the rock-beds. In a boring at Stowell, west of Temple Combe in Somerset, the upper beds of clay (not full thickness) were penetrated to a depth of 120 feet; the Fuller's Earth Rock was 35 feet thick, and the clays below 177 feet.

The soil is, for the most part, a brown and grey sticky and marly clay, that becomes much fissured in dry weather, and is heavy in wet weather, when the pasture-lands are apt to be injured by the deep footprints of cattle and horses.

The Fuller's Earth Rock yields a brown brashy clay soil or rubbly marl, on which corn, roots, and potatoes are grown. The land is in general divided by good hedge-rows, with oak, ash, etc., and there are occasional orchards. It is mostly in pasture and meadow, which vary a good deal in character, the herbage in some cases being poor, while the fields show patches of bare ground. The formation is exposed on the slopes of escarpments beneath the Great Oolite, tracts liable to landslip and often covered by tumbled blocks. It also extends over vales. Where bordering the Greensand Hills of Dorset the soil is improved by downwashes of sand. Dorset cheese is one of the products of the pastures at Mosterton.

GREAT OOLITE SERIES, MIDLAND COUNTIES.

Great Oolite Clay.

This formation, which is practically equivalent to the Forest Marble, extends from near Bicester, in Oxfordshire, to Bedfordshire, Northamptonshire, and Lincolnshire. Varying in thickness from about 5 to 40 feet, it consists of many-coloured clays—blue, green, yellow, purplish, and black—with white marl, also bands of shelly limestone (oyster-beds), lignite, seams of fibrous carbonate of lime ('beef'), ferruginous bands, and often a layer of ironstone nodules at the base, as at Overton Longville and near Oundle. Occasionally, as at Grimscote near Towcester, at Stow Nine Churches near Daventry, at Castor west of Peterborough, and at Alwalton in Huntingdonshire, there are beds that much resemble layers of hard grey or blue shelly Forest Marble. Some beds at Alwalton were polished and known as Alwalton Marble. The Great Oolite Clay is occasionally used for brick-making. The formation in general yields a clayey soil that requires draining, but it is modified in places by downwashes from Cornbrash and Kellaways Beds. The outcrop is usually narrow.

Great Oolite Limestone.

Eastwards of Burford the Great Oolite consists of a series of white, compact, earthy, and shelly limestones, partially oolitic, alternating with marls and layers full of oysters. These beds occur in the neighbourhood of Glympton, Woodstock, Bicester, and onwards to Hinton-in-the-Hedges and Towcester in Northamptonshire, thence into Lincolnshire. In this course the beds decrease in thickness from about 60 to 12 feet northwards. The term 'Great Oolite Limestone' is applied to distinguish the strata from the Great Oolite Clay. A good deal of selenite occurs in thin bands in the strata at Newport Pagnell.

Where not covered by Drift, much of the country is fairly open, with large fields, and a brashy and marly soil, under arable cultivation. Here and there the land is wooded, but most of the woodlands are on Boulder Clay.

Portland cement is manufactured from the Great Oolite Limestone and Upper Lias Clay at Irthlingborough. The stone is burnt for lime and quarried for local building-purposes in many places, as at Blisworth, Denton, Oundle, etc.

Upper Estuarine Series.

This series occurs at the base of the Great Oolite Limestone, and above the Inferior Oolite Series, in the country from North Oxfordshire to Lincolnshire.

The strata present many characters in common with those of the Great Oolite Clay, and with those of the Lower Estuarine Series in the Inferior Oolite.

They comprise white and coloured clays, blue, purple, and variegated, with sandy beds, layers of limestone, also pyrites, selenite, lignite, etc. At the base, moreover, there is frequently found a thin layer of nodular ironstone. In thickness this subdivision varies from 15 to 35 feet.

The clays are extensively worked for brick-making. White fire-clay is obtained at Wakerley, in the northern part of Northamptonshire.

The soil in general is stiff and infertile, and, when cultivated, it requires to be well drained. There are tracts of heath and common in some places, but as a rule the outcrops are not extensive, much of the formation being Drift-covered.

In Yorkshire the great mass of the strata is of Estuarine character, and the Upper Estuarine Series there includes beds of the age of the Inferior Oolite, as well as of the Great Oolite. (See p. 302.)

Representatives of the Great Oolite Series occur at Loch Staffin and elsewhere in Skye, in Raasay, and also in Sutherlandshire, where, at Brora, coal is worked.

INFERIOR OOLITE SERIES, SOUTH-WEST ENGLAND.

Inferior Oolite.

This formation in Dorset consists of hard, shelly, and oolitic limestones, some beds being highly charged with iron-ore, as at Symondsbury and Powerstock, near Bridport. The thickness varies from 6 or 7 feet to about 45 feet at Sherborne.

Near Frome the limestone is much impregnated with chert, and the soil is locally rather clayey and ochreous. In the neighbourhood of Bath the Inferior Oolite, about 40 feet thick, comprises fine-grained pale oolite, much shattered in places, and with cavities containing moulds or casts of shells. Lower down are rubbly beds of coral limestone, and at the base hard, shelly, and iron-shot limestones.

A fine sequence of strata, locally attaining a thickness of 250 feet, characterizes the Inferior Oolite of the Cotteswold Hills. There are many quarries and rich fossil-beds along the Stroud Valley and near Cheltenham, where the formation constitutes the main escarpment.

Some of the upper hard, sandy, and fossiliferous limestones or ragstones (40 feet thick) are locally known as "grits," and named from the fossils *Clypeus*, *Trigonia*, and *Gryphite Grits*. Lower beds of pale oolite supply good freestones, as at Painswick and Leckhampton, near Cheltenham, the strata including a band of Oolite Marl 5 to 10 feet thick, and attaining in places a total thickness of 150 feet. At the base is the Pea Grit Series, 25 or 30 feet thick, comprising brown ferruginous limestones and overlying layers (up to 5 feet thick) of Pea Grit or Pisolite, made up of small pea-like, but mostly bean-shaped, calcareous concretions.

Locally there are beds of dark clay and shale, calcareous sand and sandstone, from 7 to 17 feet thick, between the freestones and ragstones at Lower Harford and Snowshill, in the northern Cotteswolds.

In general the soil is a reddish-brown and brashy, friable, and calcareous loam, more marly in some places, and with a subsoil of oolite rubble.

Gentle scarps and flat-topped hills occur in Dorset, passing into more pronounced scarps northwards through Somerset to the Cotteswold Hills.

The steeper slopes, as a rule, are in meadow or pasture, and sometimes wooded. Beeches grow well on the Cotteswold scarps, and belts of Scotch fir are seen in places. Some hilly tracts, as near Bridport and Doulting, are given up to sheep-walks or sleights, and much ground is utilized as pasture for sheep on the Cotteswolds. Elsewhere corn, roots, etc., are grown on the uplands and dip-slopes. The fields are divided by stone fences and hedgerows. Good residential sites are abundant throughout the district of the Inferior Oolite.

The principal freestone quarries are at Doulting, near Shepton Mallet, Dundry, at Painswick, near Cheltenham, and other localities in the Cotteswold region. Eastwards the Chipping Norton limestone is used for building purposes, and slabs are also obtained for paving. A deep and rich soil occurs over that upland limestone country, and near Hook Norton; and the fields are mostly divided by hedgerows. Some of the stone-beds are shattered, and the rifts, or 'swillies,' are filled with clay.

Midford Beds.

This term is used for the sands, with bands and nodules of calcareous sandstone, and occasional shelly limestones, that occur between the clays of the Upper Lias and the limestones of the Inferior Oolite, from Bridport to the Cotteswold Hills. The formation includes, therefore, the following local divisions:

	Bridport Sands.	*Yeovil Sands and Ham Hill Beds.*	*Midford Sands.*	*Gloucestershire Cephalopoda Bed.*
Midford Beds	Sands with bands of calcareous sandstone, 150 feet.	Sands with bands of calcareous and shelly sandstone, passing into false-bedded shelly and sandy limestones, 130 to 200 feet.	Sands with bands of calcareous sandstone, 100 feet.	Fossiliferous iron-shot limestones and marls, 2 to 15 feet. *Cotteswold Sands.* 30 to 130 feet.

These strata form passage-beds between the Lias and the Oolites, and, when subdivided into fossil-zones, the lower horizons are grouped with the Upper Lias, and the higher horizons with the Inferior Oolite. The limits of the strata as a whole vary locally, as do those of most formations, the deposition of clay or sand having continued longer in some areas than in others. Nevertheless, for practical purposes it is most convenient to group the strata as one formation, the Midford Beds (Figs. 37 and 38).

Near Yeovil bands of shelly limestone appear in the sands, and these are well developed at Ham Hill, where they constitute the famous Ham Hill stone. Along the northern Cotteswold Hills the slopes are much covered by an accumulation of angular limestone débris, partly due to landslips, and partly ordinary waste from the scarps of Inferior Oolite, but a good deal of it is of ancient date. (See p. 209.) Some of the Cotteswold sands are very fine

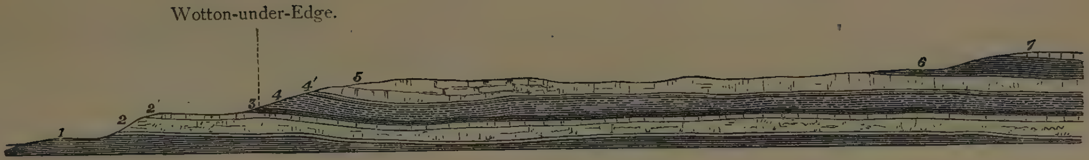

FIG. 37.—GENERAL SECTION OF THE COTTESWOLD HILLS. (A. C. Ramsay.)

2′, Marlstone
2, Sands and clays } Middle Lias.
1, Lower Lias.

4′, Cephalopoda Bed
4, Cotteswold Sands } Midford Beds.
3, Upper Lias.

7, Great Oolite.
6, Fuller's Earth.
5, Inferior Oolite.

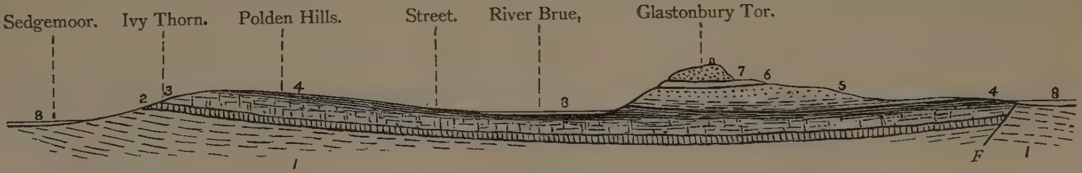

FIG. 38.—SECTION ACROSS THE POLDEN HILLS AND GLASTONBURY TOR.

2, Rhætic Beds.
1, Keuper Marls.

4, Clays
3, Limestones } Lower Lias.

6, Upper Lias.
5, Middle Lias.

F, Fault.
7, Midford Beds.

and mealy. The soil in general is a fertile, calcareous, loamy sand. In Dorset and South Somerset the outliers of the sands form conical grassy knolls, the lower slopes being sometimes cultivated, as at Glastonbury Tor. (See Fig. 38, p. 299.)

Barley and roots are grown; and oak, ash, elm, maple, etc., flourish in the hedgerows.

Deep lanes or hollow-ways are to be seen in many places.

The hilly ground formed by the Midford Beds affords many good and picturesque sites for houses.

INFERIOR OOLITE SERIES, MIDLAND COUNTIES.

In Midland regions, in the counties of Northampton, Rutland, and Lincoln, the following subdivisions are made in the Inferior Oolite Series:

Lincolnshire Limestone, with Collyweston Slate locally at base.
Lower Estuarine Series } Northampton Beds.
Northampton sands with ironstone } Northampton Beds.

Lincolnshire Limestone.

This formation consists of shelly, oolitic, and argillaceous, or earthy and compact, limestones, with scattered grains of oolite. Some of the shelly rag-beds form hard building-stone, as in the case of the Barnack Rag and Weldon Rag; the best freestones are the fine-grained oolites, as at Weldon, Ketton, Stamford, Casterton, Clipsham, Ponton, and Ancaster; the more compact stones are as a rule less durable, but good freestone of this character is quarried at Lincoln.

The Lincolnshire Limestone appears at Maidwell, and it extends thence through the north-eastern part of Northamptonshire, and onwards to Lincolnshire, attaining thicknesses of from 12 to 100 feet. At the base, at

Collyweston near Stamford, thin flaggy beds of fine-grained calcareous sandstone have been worked for roofing-purposes, under the name of *Collyweston Slates;* and in the same district the Wittering Pendle, calcareous sandy flagstone, has been used for paving. In North Lincolnshire the argillaceous limestones at Kirton Lindsey have been used for the manufacture of hydraulic lime.

In this Midland area there are some bold features, like those of the Cotteswold Hills, as along the Witham Valley, south of Grantham; and the fine scarp which extends through Lincoln, where the uplands south of the city are known as 'the Heath,' and those to the north as 'the Cliff.'

The soil is of variable depth, from a few inches to 18 inches, and is mostly a brown or red, sandy loam. Stone fences and somewhat meagre hedgerows occur on the more open tracts, but over considerable areas there are coverings of Boulder Clay, and the land is then well wooded, and the hedges are more luxuriant.

The terms 'creech-land,' or 'creechy soil,' are applied in Lincolnshire to light, brashy land, formed of a deep, red, clayey soil, with fragments of ferruginous sandstone or limestone.

With regard to sites for houses, many appropriate and picturesque localities may be found on the Lincolnshire Limestone.

Northampton Beds.

This group comprises the *Lower Estuarine Series*, white, grey, and brown sands, and clays, with ferruginous nodules, 10 to 20 feet thick; but the strata are not always to be separated from the underlying sands. The *Northampton Sands* comprise white sands, hard calcareous sandstone, sandy oolitic limestone, and the famous Northampton iron-ore. This brown iron-ore is extensively worked from near Towcester to Blisworth, Duston, and other places near Northampton, Wellingborough, Kettering, and Thrapston. It has been quarried also at Cottesmore north-east of Oakham, at Greetwell, Lincoln, and at Waltham-on-the-Wolds in Leicestershire.

Freestone, ferruginous and calcareous sandstone, has been quarried at Duston, Harleston, Desborough, Uppingham, and other places; and some flaggy beds at Duston have been used for roofing-purposes, as 'Duston Slates.'

The term 'kale' is applied to weathered beds of ferruginous sandstone in the Northampton Beds, and likewise to similar subsoil on other local formations.

The soil on the Northampton Beds is generally fertile; that on the Lower Estuarine Beds is more variable, but not so heavy as much of the soil on the Upper Estuarine Strata. The sandy and ironstone-beds yield a light, brown, or red, and more or less ferruginous soil.

Bordering the main escarpment are many outliers of Northampton Beds, which form flat-topped and often grassy hills.

GREAT AND INFERIOR OOLITE SERIES, YORKSHIRE.

The Lower Oolites of Yorkshire, which comprise beds representing the Great and Inferior Oolite Series, are very different in character from the equivalent strata in the West and South-West of England. They comprise a great series of estuarine shales and sandstones, with seams of coal and subordinate bands of marine limestone.

The Lower Oolites of Yorkshire are divided as follows:

	Thickness in Feet.
Upper Estuarine Series (in part of Great Oolite Age): Mainly shales, with bands of sandstone and ironstones; Moor Grit, massive sandstone at base	20 to 220
Grey or Scarborough Limestone Series: Grey sandy and shaly limestone, calcareous shales, sandstones, grits, and ironstones	7 to 90

	Thickness in Feet.
Middle Estuarine Series: Sandstones and shales, with many plant remains, and some seams of coal	35 to 90
Millepore Bed: Variable beds of calcareous sandstone, shales, and white oolitic limestone, with remains of the polyzoan *Millepora* (*Entalophora*), including the Cave Oolite in South Yorkshire	10 to 30
Lower Estuarine Series: Sandstones and shales, with thin seams of coal and ironstone, with Eller-Beck Bed (ironstone) and Hydraulic Limestones	50 to 300
Dogger: A variable series of sandstones, limestones, and ironstone (Rosedale magnetic ironore)	about 35
Blea Wyke Beds: Yellow, brown, and grey sandstones, and shaly layers, forming passage-beds into the Lias	70

It has been remarked by Mr. Fox Strangways* that the Estuarine Beds, which form the chief parts of the Lower Oolites in Yorkshire, constitute a coal-field that resembles, on a small scale, the important measures of Carboniferous age.

Extending over the Cleveland Hills, and containing few calcareous bands, they form the barren and exposed moor-lands, where the soil is thin, and contains, here and there, layers of hard pan. (See p. 197.) Although peaty grounds occur, especially in the western and southern parts, the land is adapted for sheep-runs in some parts. In the eastern tracts the ground has been much improved by coverings of Boulder Clay, and then it is cultivated. Again, the deep vales or dales, excavated down to the Lias, are also well cultivated where possible, or covered by woodlands.

LIAS.

The Lias comprises a great series of clays and shales, with bands and nodules of limestone, and, locally, beds of sand, sandstone, and ironstone. The strata appear at the surface over a broad belt of country between Lyme Regis in Dorset and Redcar and Whitby in Yorkshire.

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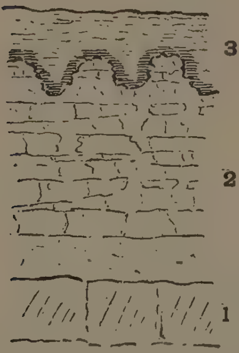
* 'Jurassic Rocks of Britain,' *Mem. Geol. Survey*, 1892, i., p. 179.

The series is divided as follows:

Upper Lias.
Middle Lias.
Lower Lias.

Upper Lias.

This formation consists of dark blue clays and shales, with nodules and bands of limestone. In Dorset and Somerset the higher beds consist of more or less sandy and micaceous shales, as well as blue clays, the formation being 70 feet thick in places.



3, Brown ochreous loamy clay, with lining of dark brown clay in hollows of decalcified Upper Lias, 2 to 3 feet.

2, Pale earthy limestones and marls (Upper Lias), broken up and rubbly in the upper part, with marl at base, and numerous Ammonites, 7 feet.

1, Brown and blue iron-shot limestone, paler at top, and crowded in places with Belemnites, etc. Marlstone (Middle Lias), 2 feet.

FIG. 39.—QUARRY WEST OF NORTON-SUB-HAMDON, WEST OF YEOVIL.

The basement-beds comprise pale, argillaceous limestones alternating with clays, and are about 6 feet or more in thickness. Near Yeovil the stone was formerly quarried for building-purposes. (See Fig. 39.) The Marlstone below is a harder and more durable rock.

The thickness of the Upper Lias clay or shale has been estimated at 200 feet near Cheltenham, 120 feet at Chipping Campden, 60 feet at Bloxham, 82 feet at Burford, 153 feet at Northampton, and 190 feet at Duston.

Along the borders of the Cotteswold Hills the slopes of Upper Lias are much covered by débris from the Oolites above, and the ground is irregular. The vales form good pasture and meadow land, and beans and corn are cultivated.

The Upper Lias in Yorkshire consists mostly of grey and dark bluish-grey shales with cement stones, and is from 210 to 250 feet thick; it includes the Alum shales, with efflorescences of alum due to the decomposition of iron pyrites and the formation of sulphuric acid, which unites with alumina to form sulphate of aluminium. At a lower horizon are the Jet shales, from which much jet has been obtained.

The Upper Lias clays are worked for brick-making at many places along their outcrop through the country.

Middle Lias.

The Middle Lias, in general, comprises a variable series of limestones, calcareous sandstones and ironstones in the upper part, to which the term Marlstone is applied. The lower strata comprise sands, shales, and clays, with some hard rock bands.

In Dorset and Somerset the following lithological divisions may be met with, but not persistently throughout the areas of Middle Lias:

Marlstone (Brown Rock or Rock Bed).
Sands and doggers of calcareous sandstone.
Laminated micaceous sands, loams, and clays.
Clays.

The maximum thickness on the Dorset coast is 345 feet.

The Marlstone, a brown, iron-shot limestone, is but a single band of rock on the Dorset coast, and in some parts of Somerset. It is more prominent at Ilminster, South Petherton, Glastonbury, and Pennard Hill. It readily decomposes along the outcrop, as near Bridport and Yeovil, into a soil of brown, friable loam, on which are grown crops of wheat, barley, turnips, potatoes, etc.

Throughout the country the Marlstone undergoes great changes, and is sometimes not at all clearly developed as a rock-bed. Near Bath it is rarely to be observed, but it is exposed in places along the lower slopes of the Cotteswold Hills. It passes into an iron-ore at Fawler, Adderbury, and King's Sutton; into a good brown and green building-stone at Hornton on Edge Hill; and again into an ironstone in Leicestershire. Below Edge Hill, in the Vale of Red Horse, near Tysoe, and near Banbury, the soil forms red lands, being a rich brown and reddish-brown friable and rubbly loam, 3 feet thick in places, the subsoil being rubbly limestone and ironstone. Near Daventry the subsoil is a rubble of iron-shot limestone, more or less friable and crumbly, with a ferruginous loamy soil containing pebbles of quartz and quartzite.

In the Vale of Catmoss (or Catmose), around Oakham in Rutlandshire, the Marlstone or Brown Rock gives rise to a rich and more or less ferruginous loam. The stone is quarried near the town, but was used in old times more largely than at present, brick buildings being now mostly erected.

The Marlstone, hard, sandy, and fossiliferous limestone, 10 feet thick, has been exposed in an outlier at Prees, in Shropshire.

In Yorkshire the Middle Lias is divided into two groups, the upper, or Ironstone Series, 100 to 120 feet thick, consisting of shales with the important beds of iron-ore at Cleveland; and the lower, or Sandy Series, about 60 feet thick, being composed of sandy shales and sandstones.

Iron-ore, equivalent to that of Cleveland, is now being worked on the Island of Raasay.

The Marlstone is quarried for road-metal, building-stone, and iron-ore, according to its local character. Red ochre, or ruddle, obtained near Ingleby Greenhow, in the Cleveland district, was formerly used for marking sheep. Pigments have been manufactured from the iron-ore at King's Sutton.

There are many brickyards in the clayey and loamy beds of the Middle Lias.

The lower clayey portion of the Middle Lias series merges downwards into the Lower Lias clays, between which there is often no definite lithological division. From an agricultural point of view the clays form one type of ground, which is mostly in meadow and pasture.

The higher sandy and loamy strata in the Middle Lias form light fertile loamy lands, and in the West of England the ground supports many orchards and vegetable gardens, excellent cider being made at Tintinhull, Cadbury, Glastonbury, and other places. Corn, roots, and potatoes are grown elsewhere, and there is much good pasture-land. The fields are divided by well-timbered hedgerows, with oak, ash, beech, and elm, as near Bridport and other places.

Good residential sites may be found generally on the higher beds of the Middle Lias, the Marlstone, and underlying sandy strata.

Lower Lias.

The Lower Lias maintains fairly uniform characters in its superficial extent from Dorset to Yorkshire.

The lower portion, known as the Blue Lias, consists of alternating blue and grey limestones and clays, marls, or shales, locally termed 'clod' in South Wales. The upper part is composed of clays and shales, with occasional bands and nodules of limestone. The thicknesses of these subdivisions vary much, as the mass of limestones, more fully developed in some places, is elsewhere in part represented by clays.

The greatest thickness of Lower Lias was proved in a boring at Mickleton, near Chipping Campden, in Gloucestershire, the total being 961 feet:

		Feet.
Lower Lias	Clays with limestones	636
	Limestones with marls, etc.	325

At Lyme Regis and Charmouth the finest coast-sections of Lower Lias are to be seen, and the total thickness is about 485 feet, comprising (at base) limestones with marls, etc., 105 feet, and clays, marls, and shales with limestones, 380 feet.

The limestone subdivision forms scarps above the outcrop of Rhætic Beds, bordering the Vale of Taunton, along the Polden Hills, etc.; while the overlying clays, together with the lower portion of the Middle Lias, form vales known as those of Marshwood in Dorset, Ilchester in Somerset, Glamorgan, Gloucester and Cheltenham, Moreton and Shipston-on-Stour, Evesham, Belvoir, etc.

Some of the uplands are locally termed 'wolds,' as Wymeswold, north-east of Loughborough, and Stanton-on-the-Wolds, south-east of Nottingham.

Near Radstock phosphatic nodules and phosphatized fossils occur in the Lower and Middle Lias, and these formations are much attenuated, the thick beds of clay being absent.

At Frodingham, in Lincolnshire, important beds of iron-ore occur in the Lower Lias. Blue Lias lime, and cement (now generally called Portland cement), are made from the limestones in many localities. Building and paving blocks are also obtained, and the stone is used for road-metal. Bricks, tiles, and pottery are manufactured from the clays.

The Lower Lias limestones, with alternating clays, yield a subsoil of broken limestone and clay, the clay occasionally becoming pale grey or white. (See p. 50.) The soil is a brashy clay or loam, yielding good pastures, much arable land, and orchards. (See p. 148.)

The Lower Lias clays have a stiff clay subsoil, and the soil is often cold and stubborn; thus the name Starve-all Farm, south of Kineton, in Warwickshire, is suggestive of a lack of fertility. Elsewhere the soil passes into a clayey loam of more fertile nature.

Much of the land, which as a rule is low-lying and flat, or gently undulating, is in pasture and meadow, as in the Vales of Moreton and Shipston-on-Stour, and around Dumbleton Hill. The Vale of Glamorgan is noted for its dairy farms, and Cheddar cheese is a product of many of the pastures to the south of the Mendip Hills.

In parts of Somerset the roads are so wet after rainy weather that raised footpaths are needed at Chilthorne Domer, Thorn Coffin, and Tintinhull. Beans, corn, flax, roots, etc., are cultivated on the Lower Lias.

Teazles were formerly grown on the Lias of Somerset and Gloucestershire for use in the West of England cloth-mills, and they are still cultivated near Ilminster.

Over considerable areas of the Midland Counties, notably in Warwickshire, there is a thin relic of Drift in the soil, forming a sandy loam, with pebbles of quartzite and quartz. (See p. 235.)

In Cumberland, to the west of Carlisle, there is a large outlying tract of Lower Lias, almost wholly concealed beneath a covering of earthy Drift gravel.

In Yorkshire the Lower Lias consists of a great series of clays and shales with bands of limestone, and in the upper part also nodules or doggers of cement-stone, some ferruginous, and layers of sandstone. The full thickness is about 720 feet. As remarked by Mr. Fox Strangways, the outcrop in the Vale of Cleveland, as at Stokesley, is much covered by Boulder Clay, gravel, and sand. Wheat and beans are cultivated, and cheese was formerly made. The beds are less covered with Drift along the southern part of the outcrop, and south of Market Weighton the limestones and clays yield a brashy clay soil that forms good arable land.

Lower Lias is well seen on the coast at Broadford in Skye, on the southern and eastern sides of Raasay, and at Golspie in Sutherland.

The 'ridge and furrow,' due to former ploughing and ridging (or bouting) of clay grounds to facilitate drainage in arable fields, now turned into permanent pasture or meadow, are features seen in many areas of Lias clay and other heavy lands.

The best residential sites in the areas of Lower Lias are naturally on the limestone series. (See Fig. 38.)

CHAPTER XXII

GEOLOGICAL FORMATIONS (*Continued*).

TRIAS AND PERMIAN—NEW RED SANDSTONE SERIES

THIS great series, characterized by red and variegated marls, calcareous and siliceous sandstones, with breccias conglomerates, loose pebble-beds, and magnesian limestone, rests in general with marked unconformity on the Carboniferous and older formations, as in Devon and West Somerset, along the Mendip Hills, in Glamorgan, and notably again from Nottingham to Tynemouth. The Permian and Trias are generally grouped as two geological systems, in which the following are the principal divisions:

Trias	Rhætic Beds.
	Keuper Marls, Sandstones, and Dolomitic Conglomerate.
	Bunter Sandstones and Pebble-beds.
Permian	Magnesian Limestone, and Marls with Sandstone.
	Red Sandstone, Breccia, and Conglomerate.

This New Red Sandstone Series forms, in some respects, a passage between the older, or Palæozoic, and the Secondary, or Mesozoic, groups. The fossils of the Magnesian Limestone tend to link it with the Carboniferous. It must, however, be borne in mind that many 'red rocks' in the central portions of England, formerly grouped as Permian, are now recognized to be Carboniferous.

From an agricultural point of view, the series, which extends from the South Devon coast through the Midland Counties to the Durham coast, is intimately associated, and has been described by Low as including 'the most continuous tract of fertile land' in England.

The characteristic feature of the New Red Sandstone Series is the dominant red colour. This is due to the presence of peroxide of iron, which coats the sand-grains, and is disseminated through the marls.

As remarked by W. H. Hudleston, it sometimes happens that the most highly coloured red rocks are most deficient in workable iron-ore, from the fact that, owing to its insoluble condition, it has not been concentrated.* Indeed, it is only locally, in fissures or other cavities or pockets of underlying Carboniferous rocks, as in Cumberland, the Forest of Dean, Llantrisant in Glamorgan, and other localities, that workable iron-ore is found in connection with the New Red rocks.

While ferruginous soils are, in general, fertile, some importance must be attributed to the colour and its power of absorbing heat-rays. (See p. 92.)

TRIAS.

Rhætic Beds.

This series, usually grouped with the Trias, is intermediate between that system and the Lias.

Where well developed, it comprises the following subdivisions:

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* *Proc. Geol. Assoc.*, 1889, xi., p. 108.

	Feet.
White Lias : White and cream-coloured limestones and marls, with hard compact limestone (Sun Bed) at top, near Bath ; Cotham or Landscape Marble near base	1 to 25
Black Shales : Dark paper shales with iron pyrites, selenite, fibrous carbonate of lime (beef) ; thin layers of limestone ; also one or more bone-beds, pebbly calcareous grit, with remains of fishes, saurians, and coprolites	8 to 36
Grey Marls : With bands of soft tea-green and buff marl, hard buff and white marl, or marly limestone, and occasionally gypsum (Passage Beds)	10 to about 100

The *White Lias* is exposed along the higher parts of the scarps, and often over portions of the flat grounds above them. It is largely under arable cultivation, the soil being a brown and brashy clay, with slabs of White Lias and Cotham Marble, especially in the area between Bath and the Mendip Hills. Southwards the White Lias is well represented at Pinhay Bay, west of Lyme Regis; but westwards, at Watchet, it is only about 8 feet thick; and it is represented by marls and a few bands of limestone in Glamorgan, North Gloucestershire, and the Midland Counties.

The *Black Shales* yield a dark grey, and sometimes reddish-brown, soil. As in the case of other dark shales, these strata have led to several fruitless trials for coal.

The *Grey Marls* yield a clayey and marly soil, good land, mostly in meadow and pasture, and not separable, unless by colour, from the land formed of the Red or Keuper Marls. In fact, while the Geological Survey originally grouped the strata with the Rhætic Beds, they have, during recent years, mapped them with the Keuper marls. They are intimately linked with the beds above and below, and a bone-bed occurs in the Grey Marls at Gold Cliff, near Newport, in Monmouthshire. Gypsum is worked at Blue Anchor, west of Watchet, and in some other localities in the Grey Marls.

The Grey Marls and Black Shales are mostly exposed on the slopes of the escarpments formed by the overlying White Lias and the Lower (Blue) Lias. (See Fig. 38, p. 299.) The best sites for residences would be met with on the White Lias.

Keuper.

This division comprises—

Upper Keuper Marls with Sandstones.
Lower Keuper Sandstone and Dolomitic Conglomerate (local).

Keuper Marls.—This formation attains a great thickness, estimated at 1,500 feet or more in some areas. It consists of red and variegated marls and clays. The marl is cuboidal in structure, readily breaking into fragments when dry.

Subordinate beds of calcareous sandstone (Upper Keuper Sandstone) occur in sundry places. They lighten and improve the land, the soil becoming loamy and pale grey or brown. The sandstones are more conspicuous in the Midland Counties, from Gloucestershire and Warwickshire (Arden Sandstone) to Leicestershire and Nottinghamshire, where they are known as 'skerries.' They also occur locally in Somerset, at Knapp and North Curry, east of Taunton, where the stone has been used for building-purposes, and at Alcombe by Minehead. At the base of the marls in Somerset, bordering the Mendip Hills, and in Glamorganshire and Gloucestershire, beds of Dolomitic Conglomerate, made up of fragments of Carboniferous Limestone in a ferruginous and dolomitic matrix, occur in association with sandstone and magnesian limestone. The conglomerate is worked at Draycott, north-west of Wells, Somerset, for building-stone.

Gypsum occurs in the Keuper Marls at Watchet in Somerset, and more important beds are found at Newark, near Nottingham, at Chellaston and Aston in Derbyshire, at Belton, north-east of Epworth, and near Stockton-on-Tees in Durham. In most of these localities the gypsum is worked for ornamental purposes, as alabaster, also for plaster, manure, etc.

Rock-salt occurs in the Keuper Marls of Cheshire, Staffordshire, and Worcestershire, and it has recently been found in a boring at Puriton, near Bridgwater. Both rock-salt and gypsum occur in the Trias at Carrickfergus, Co. Antrim.

Terra-cotta bricks are manufactured at Hathern, Leicestershire; and in many localities the Red Marls are used for brick-making.

Raddle (reddle or ruddle), which was in use in the thirteenth century (according to J. E. T. Rogers), has been worked at Winford, in Somerset, for marking sheep. Pigments are also manufactured from ferruginous beds near Doynton, in Gloucestershire.

The soils on the Keuper Marls, though sometimes wanting in calcareous ingredients, comprise deep, reddish, or reddish-brown marls, loams, and fairly stiff clays, that form rich meadows and pastures, as well as fertile, arable land. The ground in general requires draining. Dairy farms are numerous over the area, which includes parts of the Vales of Honiton and Exeter (where the soils are modified on the borders of the Blackdown Hills by downwashes of Upper Greensand), the Vale of Taunton (Taunton Dean), and the Vales of Wrington, Worcester, etc. The North and South Clay districts of Nottinghamshire, on the eastern side of the county, are mainly on Keuper Marls, the western or Sand district being that on the Bunter sands or pebble-beds.

Teazels have been cultivated on the stiffer, loamy, or marly clays, near Taunton. Strawberries are cultivated at Draycott.

The *Lower Keuper Sandstones*, which occur at the base of the Keuper Marls, are closely connected in some parts with the underlying Bunter sandstones, which are usually calcareous in South Devon and West Somerset. Clayey seams occur in the strata near Sidmouth, and along the Valley of the Otter, and the soils are deep and rich sandy loams. Some of the best apple orchards are to be seen on these sandstones in the Vales of Exeter and Taunton, and near Williton.

In the Midland Counties the term *Waterstones* has been applied to certain red and yellow flaggy sandstones and red and greenish marls and shales. These occur at the base of the Keuper Marls, and above other beds of current-bedded sandstones and breccias that were formerly grouped as Lower Keuper Sandstone or Basement Beds, but are now considered to be more nearly allied to the Bunter.* The term Lower Keuper Sandstone may therefore preferably be applied to the Waterstones, as the name was given, not on account of their being water-bearing, but because the surfaces of some of the beds had a watery appearance, like watered silk.

The Waterstone Beds yield a red clayey and sometimes calcareous, loamy soil; but the Lower Keuper Sandstones in general form a light, sandy soil. Hops were formerly cultivated at Ollerton in Nottinghamshire.

In Cumberland the Keuper formation is represented by the Kirklinton Sandstone and overlying Stanwix Marls.

The more elevated areas of Keuper Sandstone form good, dry, and healthy foundations for residences.

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* See G. W. Lamplugh, 'Geology of Newark and Nottingham,' *Mem. Geol. Survey*, 1908, p. 37.

Bunter.

The Bunter of the Midland and Northern Counties comprises a series of mottled or variegated sandstones and pebble-beds, locally capable of subdivision into Lower Mottled Sandstone, Pebble Beds, and Upper Mottled Sandstone. In many tracts, however, there is but one group of sandstones with pebbly layers at different horizons in it. In thickness the formation attains about 2,000 feet.

In Devon the strata are represented by the Budleigh Salterton pebble-bed, made up of fairly large quartzite pebbles in a sandy matrix, and about 70 feet thick. The soil—light, sandy, and pebbly, but wanting in lime—is cultivated in many places, and is famed at Wolverley, north of Kidderminster, for carrots.

Gorse-covered commons, heathy grounds and woodlands are met with over large tracts, as on Cannock Chase and Sherwood Forest. Fine residential sites characterize a good deal of the northern part of the old forest ground, 'the Dukeries,' and they may be met with in most areas on the Bunter formation. Rock-dwellings have been cut in the sandstones near Blakeshall, in Worcestershire, and near Mansfield, in Nottinghamshire.

In Cumberland, at St. Bees, and in the Vale of Eden, the Bunter is represented by fine-grained, red, brown, and white sandstone, known as the St. Bees Sandstone.

Building-stones, red and white sandstones, in part of so-called Lower Keuper Age, are obtained from Grinshill in Shropshire, Storeton, Delamere, Runcorn in Cheshire, Hollington in Staffordshire, and elsewhere, as in the case of the red Corsehill stone of Dumfries. Moulding sands are extensively worked in the Midland Counties.

PERMIAN.

Magnesian Limestone Series and Permian Sandstones, Breccias, etc.

The Permian rocks which occur in South Devon and West Somerset are intimately connected, from an agricultural point of view, with the overlying Triassic Beds. They comprise an upper series of red marls and clays, with beds of sandstone, up to 850 feet thick; and a lower series of sandstones, breccias, and conglomerates, that have been estimated to be 1,500 feet thick. The rocks are well seen in the cliffs from Budleigh Salterton to Exmouth, Dawlish, Teignmouth, and Watcombe, near Torquay. Where the breccias are adjacent to the Devonian slates and grits, as in West Somerset, there is difficulty in distinguishing the Devonian detritus, or subsoil, from the New Red Breccia, and sometimes from the newer gravelly Drift. The soils, all more or less subject to downwash, consist mostly of pale red, sandy loam, with fragments of slate, sandstone, and grit, and they resemble the cob of which mud-walls are locally built. The gravels naturally contain the more varied constituents, as they may have fragments of Lower Lias Limestone.

The soil about Sandford, near Crediton, a rich, sandy loam on the sandstones, breccias, and volcanic rocks of Permian Age, has been referred to as forming the richest land in Devonshire.*

Terra-cotta clay occurs at the base of the series at Watcombe, Torquay, and there also modelling clay has been obtained.

The Permian group, in its more characteristic form, is seen in a belt extending from Nottingham through Derbyshire, Yorkshire, and Durham to Tynemouth; and it can well be studied on the coast from Hartlepool to Sunderland, Marsden, and South Shields. It comprises—

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* H. Tanner, *Journ. Roy. Agric. Soc.*, 1848, ix., p. 458.

Magnesian Limestone and Marls, with sandstone and gypsum.
Marl Slates.
Quicksand.

The higher beds of marl, etc., appear in places to be intimately linked with the Bunter Beds, as pointed out in Nottinghamshire by Dr. R. L. Sherlock. There the soil varies from clay to loam.

The *Magnesian Limestone* comprises a series, 500 or 600 feet thick, of limestones and dolomitic limestones, some with remarkable concretionary structures, some brecciated, alternating with sandy limestones, sandstones, and marls. At the base is the *Marl Slate*, a laminated, shaly limestone, 5 to 30 feet thick.

The Magnesian Limestone yields variable soils; in places a light, dry soil, thin and brashy, and somewhat hungry, forms arable land on which barley, turnips, etc., are cultivated. A brown, loamy, and clayey soil is elsewhere found, with pastures and meadows, noted for bright green verdure in early summer, and including good grazing-land between Staindrop and Darlington.

On deeper soils, to some extent a downwash on slopes, near Pontefract, there has been grown much liquorice, the roots of which are 2 or 3 feet in length.* In some places the soil is formed of dolomitic sand.

Quicksand, fine yellow running sand, irregular and impersistent, occurs at the bottom of the Magnesian Limestone Series in Yorkshire. It appears to be due in some cases to decalcification of the limestone. It has been used for moulding purposes at Pontefract and Glass Houghton.

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* J. H. Charnock, *Journ. Roy. Agric. Soc.*, 1848, ix., p. 297.

Building-stones form an important product of the Magnesian Limestone, and have been worked at Mansfield Woodhouse, Bolsover, near Worksop in Nottinghamshire, and at North Anston, Roche Abbey, and other places in Yorkshire. In Nottinghamshire, also, the Red and White Mansfield (Dolomitic) Sandstones have been much quarried.

In Cumberland there is a considerable thickness of Permian rocks in the Vale of Eden, and an attenuated series, 40 to 50 feet thick, on the coast near St. Bees. The upper strata, 300 feet and more in thickness, consist mainly of red marls and shales with gypsum, and include beds of Magnesian Limestone; the lower strata comprise beds of breccia, 100 to 150 feet thick, locally known as 'brockram,' and formed, like the Dolomitic Conglomerate of the West of England and South Wales, of fragments of Carboniferous Limestone in a red, sandy matrix. The breccia occurs at two horizons, with intervening Penrith Sandstone, a bright red, false-bedded sandstone, 300 to 1,000 feet thick. The Penrith Sandstone and the Brockram are quarried for building-stone, and the latter is also burnt for lime.

The sandstones and Magnesian Limestones of the Permian form land that is usually well adapted for residences.

CHAPTER XXIII

GEOLOGICAL FORMATIONS (*Continued*).

4. UPPER PALÆOZOIC

Between the Secondary or Mesozoic formations and those of greater antiquity, there is evidence in Britain, as a rule, of great discordance. For the sake of convenience, the Permian and Triassic rocks have been grouped together, as they constitute a great New Red Sandstone Series; and, moreover, prior to their deposition, the later of the Palæozoic rocks were subjected to considerable disturbances and much erosion, as shown, for example, in the denuded anticlines of the Mendip and Pennine Hills (Fig. 40), and in the great basins or synclines in which many coal-fields have been preserved. (See Figs. 40 and 42.)

The older Palæozoic rocks have suffered far more disturbance, folding, and erosion, at successive periods, especially those of pre-Silurian Age.

In general the older Palæozoic and the Archæan formations, together with the larger tracts of igneous rock of diverse ages, constitute the more elevated and less fertile regions. They extend over a large part of western and northern England, Wales, the southern uplands of Scotland, the Isle of Man, the borders of Ireland (see Plate I.), and elsewhere. There is far less arable land and meadow, but much hill-pasture and rough grazing-ground, occupied as pastoral or hill farms with sheep-runs; there are also bare, rocky, and craggy tracts; and other areas with thin soils of sandy and stony loam on a rocky subsoil, or with hill or mountain peat, from a few inches up to 30 feet in thickness. Boulder Clay and Drift Gravel occur on some of the moor-lands and mountain slopes, and also, with alluvial tracts, along the valleys, which in many places are well cultivated. On the lower grounds of the Palæozoic rocks, as in Pembrokeshire and Carmarthenshire and other parts of Wales, and in Corve Dale, Shropshire, there is much pasture and arable land, with light, loamy soils suitable for barley, etc.

The sequence and thicknesses of the main divisions of the older rocks are given in the Table (p. 11); but it may be added that the results of recent researches have been to create numerous local subdivisions in the strata. The great systems, indeed, are all capable of many local lithological subdivisions, which are now represented on the 6-inch maps of the Geological Survey; but particular accounts of these would increase this volume to undue limits, and the details would not be so important from agricultural and sanitary points of view as those relating to the Secondary and newer formations. As a rule, sites for residences are dependent more on elevation and aspect than on the soil and substrata, especially on the Lower Palæozoic and older rocks, and it will be sufficient to give their general lithological characters.

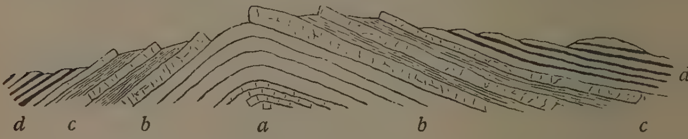

Fig. 40.—Section across the Pennine Anticline. (J. W. Davis.)

b, Yoredale Series.
a, Carboniferous Limestone.
d, Coal Measures.
c, Millstone Grit.

This section is diagrammatic, the outcrops of the grit-beds being exaggerated.

The newer Palæozoic rocks include the Carboniferous system, with large areas of thick limestone, and all the important coal-fields; also the Devonian and Old Red Sandstone. The older Palæozoic include the Silurian, Ordovician, and Cambrian, which comprise a great series of slates, mudstones and shales, sandstones, flags, grits, quartzites, and conglomerates, with some limestones, and many igneous rocks, both intrusive and interbedded.

In the early days of geology the term 'Greywacke' (or 'Grauwacke') was applied generally to these older formations, including the Devonian, before the sequence of the subdivisions had been determined.

CARBONIFEROUS.

This system is generally divided as follows:

Coal Measures.
Millstone Grit.

Carboniferous Limestone Series	Upper Limestone Shales, Pendleside and Yoredale Beds. Carboniferous Limestone. Lower Limestone Shales and Calciferous Sandstone.

Coal Measures.

This formation comprises a great series of dark grey clays and shales, sandstones, with seams of coal, layers of ironstone, and occasional thin bands of limestone. In the upper part, however, there are red sandstones, clays, and marls much resembling Permian strata. (See p. 312.) The character of the coals varies according to the amount of carbon, from about 78 to 95 per cent. and more, in passing from ordinary coal to anthracite.

The detailed subdivisions of the Coal Measures differ considerably in the many coal-fields; but it has usually been found convenient to divide into a Lower, Middle, and Upper Series, without implying that they can be closely correlated in the various areas.

In South Wales, the Forest of Dean, Somerset and Gloucester, there is a great central division of practically barren Pennant Grit, a group composed mainly of hard, red, grey, and green sandstones and grits. It attains a thickness of 3,000 feet, and forms bold and elevated moorland tracts in South Wales. In the Forest of Dean the coal-field generally is characterized by wood-lands; in Somerset, on the other hand, the coal-field is but little exposed, and the area is mostly under cultivation, with arable and meadow land, and some wood-lands on the Pennant Grit. In South Staffordshire the coal-field, known as the 'Black Country,' is desolate; while much of that in North Staffordshire, known as the 'Potteries,' has lost its natural beauty. The great Yorkshire coal-field, with many bold and picturesque features, is now known to extend, within workable depths, below the rural districts of the neighbourhood of Doncaster and towards the Trent Valley farther south. The Cumberland or Whitehaven coal-field extends from the mainland beneath the sea. In Northumberland coal is worked in the Carboniferous Limestone Series as well as in the Coal Measures, and in Scotland it occurs in all the divisions of the Carboniferous.

In Devon and Cornwall there is a great and barren series, known under the name of the 'Culm Measures.' The lower strata belong to the Yoredale or Pendleside Series. (See p. 328.) The Upper and Middle divisions, which represent the Coal Measures (in part) and Millstone Grit, consist of shales and sandstones, with seams of culm or anthracite, in the Upper division, near Bideford. The strata in general have been greatly disturbed, faulted, and bent into numerous folds. The land, as a rule, is characterized by poor soils of yellow and white clay, with subsoil of shillet or shale, that requires draining; and elsewhere of sand, with fragments of grit and sandstone. It was remarked by Sedgwick and Murchison* that sulphate of iron, derived from the yellow pyritous clays, 'where it meets with the roots of the oak, sometimes produces streams of natural ink, which discolour the deep cuttings of the soil by the sides of the cross roads to a considerable distance.' They refer, also, to a highly carbonaceous shale near Bideford, that was used as a black pigment, known as 'Bideford Black.'

Very red, sandy, ferruginous soils occur in some areas, as on the Pennant Grit, in Somerset, near Pensford, and it is difficult to mark out the areas occupied by the Coal Measures and those where the Keuper Marls and Sandstones come to the surface.

Pine for pit-timber is grown on some of the steep hillsides in the grit and sandstone areas, and oak and other trees grow on the clayey and shaly tracts. In general there is a deficiency of lime in the soils. The clay tracts yield a yellowish clay that is cold and poor in quality; the sandstones yield a sandy or sandy loam soil. Most of the soils are regarded as naturally barren and 'ungrateful,' and where there are alterations of shale and sandstone the ground is liable to contain many springs. There are, however, areas of more productive, friable, clayey, and sandy loam.

Apart from the various kinds of coal obtained in different areas and the oil-shale, the Coal Measures contain bands of ironstone (iron carbonate), with much coaly matter, and known as 'black-band.'

Fire-clay is obtained from the underclay, or seat-earth beneath coal-seams, and is used for the manufacture of fire-bricks. Various clays, including the Etruria Marls of North Staffordshire, are used for brick-making, etc. Harder beds of seat-earth, fine-grained, siliceous sandstones, known as 'Ganister' (or 'Gannister'), occur in the Lower Coal Series of Yorkshire, Lancashire, and Coalbrookdale; hence that division is known as the 'Ganister Series.' The rock has been used for road-metal. Building-stone and paving-stone have been obtained from many of the sandstones in the Coal Measures. The yellow sandstones of Potter Newton and Chapel Allerton, near Leeds, have been pounded into sand for sprinkling kitchen-floors. The best sites for residences are, as a rule, to be found on the thicker masses of sandstone.

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* *Trans. Geol. Soc.*, series 2, 1840, v., p. 679.

Millstone Grit.

This formation consists of hard sandstones or grits, quartzite, conglomerate, and shales, the uppermost beds being known in the South-West of England and South Wales as the 'Farewell Rock,' because no coal is usually to be worked below.

Much of the country occupied by the Millstone Grit in Derbyshire, Lancashire, Yorkshire, and Durham, is high moor-land, with scattered blocks and many scarps and crags of grit, as on Brimham Moor, east of Pateley Bridge. (See also Fig. 41.) The lower slopes, with stony soil, form enclosed grass-lands. Many fine reservoir sites have been obtained in the Millstone Grit and Yoredale Beds along various parts of the Pennine Hills. Here and there prominent outliers of Millstone Grit form mountains, as Whernside, said by John Phillips to have been anciently 'Quernside,' because querns could be cut from the rock; also Ingleborough and Penyghent.

Five principal grit rocks have been generally recognized in the formation in Derbyshire, Staffordshire, etc. They occur in descending order as follows:

1, Rough Rock.
2, Haslingden Flags.
3, Chatsworth or Rivelin and Roaches Grits.
4, Kinder Scout Grit.
5, Shale (formerly Yoredale) Grit.

These are separated by shales, sometimes near the surface by way-bands of clay, and, when the strata are inclined towards a valley, there is a tendency to land-slipping.

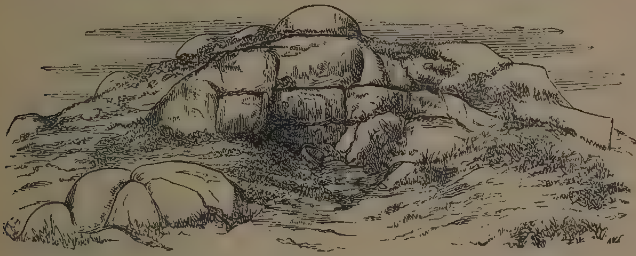

FIG. 41.—MILLSTONE GRIT NEAR YSTRAD-FELLTE, BRECON. (T. W. Edgeworth David.)
Rocks smoothed by ice-action (*Roches moutonnées*).

In the Bristol district the Millstone Grit is for the most part a hard quartzite with ferruginous specks, but it includes shales.

In the Vale of Neath and near Llanelly silica stone and silica clay (or 'plastic clay') have been worked for the manufacture of fire-bricks. The Dinas fire-bricks are made from silica stone, a tough quartzite, consisting of 95 to 97 per cent. of silica; but the stone, after being crushed, is mixed with a little clay and milk of lime. The so-called 'plastic clay' is described by Dr. A. Strahan as an impalpably fine siliceous sand.*

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* See 'Geology of Ammanford,' 1907, pp. 75, 218, and 'Geology of Carmarthen,' 1909, p. 156, *Mem. Geol. Survey*.

In the Northern Counties the Millstone Grit yields much building-stone, and in former days supplied much paving-material—the Yorkshire paving-stones. Artificial pavement, which is made in slabs of uniform thickness and is not liable to flake off, has largely replaced the natural flagstone.

Yoredale Series, including Upper Limestone Shales and Pendleside Beds.

In the West of England and South Wales, between the Millstone Grit and Carboniferous Limestone, there is a series of shales with bands of limestone and chert, termed the 'Upper Limestone Shales'; and in Devonshire and West Somerset the lower part of the Culm Measures, which belongs to the same series, contains beds of limestone and chert at Codden Hill, near Barnstaple, and limestones at Bampton, and between Tiverton and Wellington. In Flintshire, beds of chert, etc., that have been grouped as Millstone Grit, are considered by Dr. Wheelton Hind and Mr. J. T. Stobbs to belong to the same formation.

In Derbyshire, Staffordshire, and Lancashire, the strata usually grouped as Yoredale Beds have been regarded by Dr. Hind as belonging to a higher horizon than the Yoredale Beds of Wensleydale (which he classes with the upper part of the Carboniferous Limestone), and he has therefore given the name Pendleside Series to this presumably newer division, or Upper Limestone Shales. (See Fig. 42.)

In Derbyshire, etc., the strata form two main subdivisions, as follows:

Sandstones, with black shales and Crowstones (hard, fine-grained sandstones or quartzites).
Black Shales, with layers and nodules of limestone.

The Black Shales are well seen in the 'shivering mountain' of Mam Tor, north-west of Castleton.

In Lancashire, according to Mr. R. H. Tiddeman,* the sequence below the Millstone Grit is as follows:

Bowland Shales (bituminous).
Pendleside Limestone.
Shales and limestones.
Clitheroe Limestone.

In Yorkshire the Yoredale Beds (of Yoredale or Wensleydale) comprise shales, sandstones, flagstones, grits, limestones, chert, and seams of coal. Many of the limestones are remarkably persistent. There is no very definite plane of division between the Yoredale Beds and the Carboniferous Limestone, and the same conditions are maintained through Durham, Northumberland, and Cumberland.

The chert-beds have been quarried in Yorkshire and other places for use in potteries, for road-metal, etc. The limestones are burnt for lime, and utilized for building-purposes. Some beds yield crinoidal marble.

The crowstones are used for road-metal, but not as building-stone. Flagstones, sandstones, and grits, are employed for building and paving purposes.

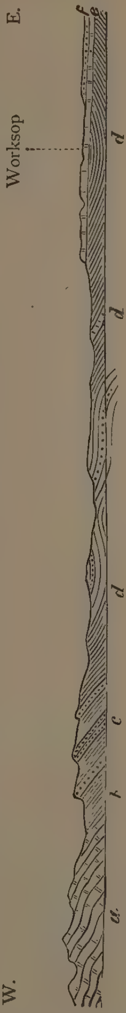

FIG. 42.—GENERAL SECTION ACROSS THE DERBYSHIRE COAL-FIELD. Length 25 miles. (E. Hull.)

b, Yoredale (Pendleside) Series. *d*, Coal Measures. *f*, Trias.
a, Carboniferous Limestone. *c*, Millstone Grit. *e*, Magnesian Limestone (Permian).

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* 'Geology in the Field,' *Geol. Assoc.*, 1910, p. 648.

Slates at Tracebridge, in Somerset, in the Lower Culm Measures, have been quarried for roofing-purposes.

The 'Lead Measures' of Alston Moor in Cumberland, Weardale, Wensleydale, etc., belong to the Yoredale Series. Manganese-ore occurs in the limestones at Bampton, in Devon.

Carboniferous Limestone.

This formation is termed the 'Mountain Limestone,' because it often forms mountainous ground, as in Sligo and in many parts of the North of England and South Wales. Appearing often in bare crags, it is known also as the 'Scar Limestone' in the North of England.

It is characterized by rocky combes, as in the Cheddar Cliffs, the Avon gorge at Bristol, the dales of Derbyshire, the glens of Roslin and Hawthornden, near Edinburgh, and by numerous caverns. It nevertheless occurs, like most other formations, at various levels, and in Central Ireland it occupies the plains beneath much Drift and Peat. The higher grounds are usually dry, as the water descends underground through fissures, caverns, and swallow-holes, to be given out at lower levels. It comprises a great series of hard, blue, bluish-grey and pale grey limestones, with some pale oolitic beds. Some layers are bituminous, and emit an odour when struck with the hammer. Chert occurs in irregular nodules and bands.

The soil is red and clayey or marly, sometimes only 1 to 3 inches thick, with bare rock jutting out here and there. The soil is liable in all districts to be washed away in fissures in exposed situations. It generally yields short and sweet herbage for sheep, and, on the deeper soils, wheat, oats, and roots, are cultivated. Among trees the ash is prominent on Mendip, and there are plantations of pine, spruce, larch, beech, and sycamore. There are ash copses on some of the screes. (See Fig. 4, p. 63.)

North of Derbyshire the limestones become more and more intercalated with shales and sandstones, and many of the uplands are barren, peaty, and heathery tracts. The areas of good pasture and arable land are mostly on the deeper soils in the valleys. The character of both upland and valley is modified in many places by Drifts.

Nevertheless, in the Yorkshire dales and in Durham there is good limestone pasture for cattle up to 1,000 feet, and among the products are Wensleydale cheese and Swaledale butter. The sandstones and shales, and the areas covered by Drift clay produce coarser grass-lands on the higher elevations.

Hugh Miller, jun., noted on the uplands of Otterburn and Elsdon in Northumberland that there is dark heather and 'white ground,' so termed by shepherds, as the coarse grasses lie more or less bleached for seven or eight months in the year. The green, grassy strips that are found on the outcrops of limestones are known as 'gairs.'

On some of the uplands there are remarkably bare tracts of limestone, known as 'helks' and 'clints,' in West Yorkshire and the Lake District. The limestone, mostly horizontal, is traversed by open fissures (gilles, grykes, or grikes), and the ground is devoid of soil, except in some of the joints and cracks where vegetation can grow. These areas might be termed the 'bad lands' of England, from an agricultural point of view. (See Plate II., Fig. ii.)

In Ireland the decomposition of the limestone and sandy limestones give rise to red earth, yellowish-brown, clayey, and sandy loams, and sometimes to loose, dry, brashy ground. The term 'calp' is applied to impure, argillaceous limestones and shales that occur locally in the central part of the Carboniferous Limestone.

In Galway and elsewhere the land is strewn with many great blocks of limestone; much bare rock also occurs, and, as the fields are bounded by stone fences, the land has a very stony appearance.

On approaching the Aran Islands, as observed by Mr. P. B. Mason, 'they present the appearance of undulating stone-fields,' and, with the excessive rainfall, the surface of the limestone is so rapidly dissolved away that no plants can find lodgment on the surface. Many ferns, however, contrive to exist in the fissures. 'The only parts that can be cultivated are the slopes where talus can lodge, and the places which have been covered by the drifting sand.' On these scanty patches potatoes and grass are cultivated, with the help of seaweed manure. Layers of sand and seaweed have sometimes been carried on to bare tracts of limestone to form a soil. There is no bog or peat fuel.*

In parts of South Wales and in Derbyshire (where it is known as 'dunstone'), the limestone is locally converted into dolomite.

Fluor-spar (calcium fluoride), known as 'Blue John,' has been worked at Castleton in Derbyshire. Barytes (barium sulphate) is worked for pigments (permanent white). Lead-ore (galena or sulphide of lead) has been worked on the Mendips, in Derbyshire, Flintshire, etc.

The limestone is extensively used in Ireland for building-stone—Kilkenny is known as the 'Marble City.' In England and Wales it is also used for building-purposes, for lime, and road-metal. It yields a good white lime, suitable for agricultural purposes.

In Derbyshire the Hopton Wood Stone, a crinoidal and shelly limestone, is polished as marble, and also used for paving-purposes. An oolitic limestone, known as 'Clee Hill Marble,' is locally obtained from the Carboniferous Limestone.

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* *Midland Naturalist*, 1891, xiv., p. 49.

Lower Limestone Shales.

On the Mendip area a series of shales, in places 300 feet in thickness, occurs beneath the Carboniferous Limestone. Near the junction the shales contain alternating beds of limestone, and lower down alternating beds of sandstone and shale form a passage into the Old Red Sandstone.

This clayey division supports ponds and furnishes a deep, clayey, and loamy soil. Swallow-holes occur at the junction with the Carboniferous Limestone on the Mendip Hills.

The Lower Limestone Shales occur in South Wales, but there they are more variable in character, and the included limestones are often much thicker than in Somerset.

Equivalent strata in Northumberland have been classed as Tuedian; they consist of shales, calcareous sandstones, limestones, and cement-stones, 800 feet and more in thickness. In Scotland the strata are included in the Calciferous Sandstone Series, above the Old Red Sandstone, and comprise sandstones, black shales, thin limestones, and a few coal-seams.

OLD RED SANDSTONE AND DEVONIAN.

Under these terms are included two phases of one geological system, which, from a chronological point of view, is best termed 'the Devonian.' That group is essentially a marine series, whereas the Old Red Sandstone represents lacustrine and estuarine conditions.

Old Red Sandstone.

The Old Red Sandstone comprises a thick series of red, grey, and yellow sandstones, red marls, that are sometimes micaceous, and contain a good deal of very fine sand, calcareous concretionary beds known as 'cornstones,' conglomerates, and, locally, beds of flagstone.

In some areas, as in Carmarthenshire and Breconshire, Monmouthshire, South-West Ireland, and Sutherland, the formation attains high elevations, forming mountainous moor and heath lands. In the less elevated regions along the Welsh and English borders, especially on the red, sandy marls, with cornstones, it yields deep and fertile red soils.

Naturally, the soil varies from a rich and mellow loam and sandy marl to fairly strong clay in some places; in others the soil is loose and sandy; and where the conglomerate has been disintegrated into a gravel, there results a somewhat hungry soil.

In the northern part of the Forest of Dean, on the borders of Gloucester and Hereford, the sandy tracts, with a soil of 'keen sand,' that extend to Dymock, Newent and Pauntley, partly on Old Red and partly on New Red (Keuper) Sandstones, were known as the 'Ryelands,' because rye was much cultivated, and it was considered 'that the poorest land will bear rye.' *

A generally fertile soil is found in the Teme Valley between Ludlow and Tenbury, where hop-grounds, orchards, etc., flourish. There are also large areas of excellent pasture and meadow land, and much ground where barley and other crops are cultivated.

Corve Dale, between Wenlock Edge and the Clee Hills, is a fertile area, partly on Silurian, and partly on Old Red Sandstone.

On the Mendip Hills, near the Downhead Monument, the soil consists in places of from 2 to 3 feet of peaty mould, and elsewhere of grey, sandy soil, with quartz and other pebbles, overlying yellowish-brown and purplish gravel, 5 feet thick, and due to the disintegration of the Old Red Conglomerate.

Some of the best lands in Scotland are formed of Old

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* T. Rudge, 'Agriculture of Gloucester,' 1813, p. 138.

Red Sandstone, as the Howe of Fife or Stratheden, which extends through Cupar; the great Vale of Strathmore, which crosses the country from Dumbarton to Montrose and Stonehaven; the lands bordering the Moray Firth, and especially those of the Plain of Ross, including the Black Isle, south of Cromarty, and Easter Ross, which extends to the borders of Dornoch Firth. In these areas, however, there are modifying influences in the coverings of Drift clay and gravel.

Old Red Sandstone has been used for building-purposes at Cradley, west of Malvern, between Ludlow and Onibury, where it is sometimes termed 'dunstone,' also in Fifeshire, Forfarshire, and other localities. The marls have been used for brick-making.

Devonian.

The Devonian system comprises a great series of red and grey sandstones and grits, slates and shales, with thin limestones in Cornwall, North Devon, and West Somerset, and thicker masses of limestone at Newton Abbot, Torquay, and Plymouth.

The general grouping in the northern and southern areas is as follows :*

	South.	*North.*
Upper	Slates and limestones.	Pilton, Baggy, and Marwood Beds (flaggy sandstones, grits, and slates; also nodular limestones in Pilton Beds). Pickwell Down Sandstones.
Middle	Torquay and Plymouth Limestones and Slates.	Morte Slates (?). Ilfracombe Beds (slates with thin limestones).
Lower	Staddon Grits.	Hangman Grits.
	Meadfoot Beds (grits and slates).	Lynton Beds (slates with grits).
	Dartmouth Slates.	Foreland Grits.

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* Ussher, 'Geology in the Field' (*Geol. Assoc.*, 1910, p. 864).

The true age and stratigraphical position of the Morte Slates have been questioned by Dr. H. Hicks, who regarded them as in part Lower Devonian, and in part Silurian.

In North Devon and West Somerset the country is largely made up of bold and comparatively smooth ranges of hills, forming the Quantock and Exmoor Ranges. The summits of the higher grounds are moory and destitute of trees, with heather and tracts of grass and gorse, but they are in many places well wooded on the lower slopes.

The ground is cultivated at varying levels, according to the nature of the slopes. The soil on the areas of sandstone and grit is hard, coarse and fine angular detritus, with sandy loam, having some of the characters of gravel land, but not generally very fertile, although the land as a whole is regarded as better than that on the grits and shales of the Culm Measures. The subsoil consists sometimes of 6 feet of broken grit, not readily decomposed. On the lower portions of the steeper slopes there are thicker accumulations of angular stones.

Oaks send their roots deeply into the ground in the loose material, and in crevices of the less broken rock below.

The slates form a clayey soil where decomposed, otherwise the ground, made up of slaty fragments, is loose and porous. Some of the better lands are along the horizon of the Ilfracombe Beds, which contain thin limestone seams and calcareous slates; and also in the highest part of the Devonian series, near Barnstaple. Some of the poorest lands are those in the mining districts of Cornwall, where the ground is often barren and bleak, with few trees, and where the rocks contain numerous quartz-veins. Fragments of these occur in the soil so abundantly, as noted by De la Beche, near St. Agnes, that it was necessary to clear the land from the stones in order to cultivate it.

In South Devon and Cornwall, where slaty areas prevail, the rocks are known under the general term of 'killas.' The soil consists of clay, with fragments of shivery shale and slate, and much land consists of bold, rounded hills, as near Looe. It is largely under grass and tillage, with well-timbered hedgerows, as near Launceston. On the surface there are occasional rocky protuberances, and the soil is fairly dry, as a rule, owing to natural drainage. Some of the better lands are in the region of the red slates of Fowey and eastwards, where the soil is suitable for orchards.

The limestones of Newton Abbot, Torquay, and Plymouth, form rocky tracts, with comparatively little soil; while the sandstones and grits, as in North Devon, are not naturally fertile.

In the district of South Hams, sometimes taken to include all the land south of Chudleigh, from Plymouth in the west to Torbay on the east, the soil in general is very fertile, and affords good grazing land for cattle. It is composed of calcareous clays and light loams, and where the Aspringtonvolcanic series occurs, to the south-east of Totnes, the red soil supports some

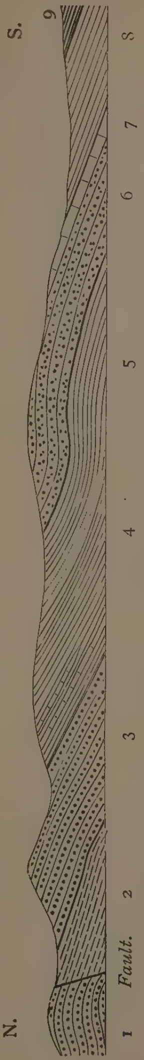

Fig. 43.—General Section across the Devonian Rocks of North Devon.

3, Hangman Grits. 6, Pickwell Down Sandstones. 9, Culm Measures.
2, Lynton Beds. 5, Morte Slates. 8, Pilton Beds.
1, Foreland Grits. 4, Ilfracombe Beds. 7, Baggy and Marwood Beds.

of the best arable and grass land. Elsewhere the slates, hardened and altered by igneous rocks, are infertile; but around Salcombe, on the area of mica-schists (regarded as Archæan), there is excellent arable and also pasture land.

Near Ellacombe, Torquay, the limestone is dolomitic, and is disintegrated into a loose dolomitic sand.

Sedgwick and Murchison noted that in Devon the term 'shillet' (or 'shillat') was applied to soft, earthy slate, 'pavey' to glossy and unctuous slate, and 'trug' to beds of red limestone.

Slates have been extensively quarried at Delabole, west of Camelford, at Tintagel, and elsewhere, for local purposes, as in the Morte Slates at Oakhampton Quarry, north of Wiveliscombe.

Apart from the various metalliferous lodes and veins worked in Cornwall and Devon, it may be mentioned that iron-ore (carbonate) has been worked in the Morte Slates of the Brendon Hills. Pigments have been manufactured from the red and brown iron-ores at Brixham.

The limestones are quarried for building-stone, marble, lime-burning, and road-metal, especially at Newton Abbot, Torquay, and Plymouth.

It may be mentioned that among areas suggested for afforestation, are the unsightly tips or spoil-heaps of refuse from mines, slate-quarries, etc.

CHAPTER XXIV

GEOLOGICAL FORMATIONS (*Continued*).

5. LOWER PALÆOZOIC, PRE-CAMBRIAN AND ARCHÆAN

Silurian.

In this system the main divisions in England and Wales are as follows:

	Wales and English Borders.		*Lake District.*
Ludlow Series	Downton Sandstone		Kirkby Moor Flags.
	Upper Ludlow Shales		
	Aymestry Limestone	Denbighshire Grits and Flags	Bannisdale Slates, Coniston Grits and Flags.
	Lower Ludlow Shales		
Wenlock Series	Wenlock Limestone		
	Wenlock Shale		
	Woolhope Limestone		
May Hill Series	Tarannon Shales		Stockdale Shales, etc.
	Llandovery Beds (sandstones, grits, conglomerates, and shales)		

The more regular belts of Silurian are to be seen in the country which extends from near Wenlock to Ludlow, and includes the fine escarpment of Wenlock Edge (Wenlock Limestone), and the lesser escarpment of the Aymestry Limestone.

Some of the limestones are sandy, and yield light calcareous loamy soils. Good grass-lands are to be found on the calcareous and sandy shales of the Ludlow Beds.

The limestones are quarried for lime-burning, and in some places for cement-making. The Wenlock Limestone, which contains large concretionary masses of purer limestone, known as 'ballstones,' has been utilized at Dudley and elsewhere in Staffordshire as a flux for iron-smelting. The Downton Sandstones are quarried for building-purposes, and the grits and flags of Denbighshire and the Lake District are used for building and paving. Flaggy micaceous sandstones, known as 'tilestones,' which occur at the top of the Ludlow Beds in Carmarthenshire, were formerly worked for roofing-purposes.

Ordovician.

The main divisions of this system in England and Wales are as follows:

Wales and English Borders.	*Lake District.*
Bala Series, including Caradoc Sandstone (shales, flags, and limestones; also volcanic rocks).	Coniston Limestone Series, with Ashgill Shales at top.
Llandeilo Series (slates and flags, with limestones and volcanic rocks).	Borrowdale Volcanic Series.
Arenig Series (slates, flags, grits, and quartzites, with volcanic rocks.)	Skiddaw Slates (in part).

Limestones are not very prominent. In the Llandeilo Beds they occur near Llandeilo, and in the Bala Series at Narberth and Robeston Wathen in Pembrokeshire, also at Bala. They are represented also at Coniston in Lancashire, and other parts of the Lake District. The limestones are burnt for lime.

The soft Skiddaw Slates have been manufactured into slate-pencils at Shap and other places.

The Arenig and Llandeilo Beds yield slates and flags.

Cambrian.

The Cambrian system comprises slates, flags, grits, quartzites, and conglomerates, and includes the famous slates worked at Penrhyn and Llanberis, and those of Ffestiniog.

The highest beds are the Tremadoc Slates, which are regarded as including the Grey Shales of Malvern and the Shineton Shales of Shropshire. Beneath is the Lingula Flag Series, which includes, in the upper part, the Black Shales of Malvern. Then come the Menevian Beds (sandstones, shales, and flags). The lowest strata include the Solva Beds (flags and grits) and the Caerfai Beds (sandstones, shales, and conglomerates) of Pembrokeshire, the Harlech Grits and Llanberis Slates of North Wales, the Hollybush Sandstone of Malvern, the Comley Beds (conglomerate, limestone, and sandstone) of Shropshire, and the Hartshill quartzite of Warwickshire.

The Stockingford Shales of Warwickshire, and the Durness Limestone of North-West Scotland, include strata on the horizons of the Menevian Beds, Lingula Flags, and Tremadoc Slates.*

Some of the older beds of killas in West Cornwall, as indicated by Mr. J. B. Hill, may be of early Palæozoic age, but no fossils have been found to determine this question.

They include the Portscatho Series, consisting of blue and grey slates with bands of grit, which yields in places good loamy soils, though the steep slopes are nearly bare.

The Falmouth Series, which consists of variegated sandy beds, shales, and slates, forms the best land, as the strata are readily decomposed by weathering agents.

The Mylor Series, which occurs in proximity to the granite, is composed of fine-grained slates, with quartz veins and interlaminations of siliceous and argillaceous material, giving a striped appearance. It yields a soil with a good deal of quartz débris, and much of the land is out of cultivation.

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* See P. Lake and R. H. Rastall, 'Textbook of Geology,' 1910, p. 312.

Pre-Cambrian and Archæan.

Researches in various parts of the world indicate that the oldest Pre-Cambrian and Archæan rocks are mostly of a crystalline and schistose nature, such as mica-schists, talc-schists, chlorite-schists, hornblende-schists, and granites or granitoid rocks that have been altered into gneisses. Associated with them, also, are quartzites and limestones.

In general it has been found impossible to determine the order of succession in time of the subdivisions in these metamorphic rocks, as, although a sequence may locally be proved, it is not evident which is the uppermost in natural order. Such is the case in the vast assemblage or complex of rocks known as the Highland or Dalradian Schists, partly igneous, partly sedimentary, and all highly altered. These rocks, and the Lewisian gneiss of the Hebrides, are mostly barren, with thin, stony, and peaty soils, and sometimes no surface soil; elsewhere, however, decomposed mica-schists and other rocks yield a fairly good loamy soil.

The gneiss of Malvern, granitoid rocks in Pembrokeshire and Carnarvonshire, various schists in Anglesey, and those of Bolt Head and Start Point in South Devon, are among those grouped as Archæan. Ancient volcanic rocks of pre-Cambrian Age, known as Pebidian and Uriconian, are found in Pembrokeshire, near St. David's, and at the Wrekin. In Charnwood Forest there is a series of igneous and sedimentary rocks, agglomerates and hornstones, slates, quartzites, grits, and conglomerate, many of the rocks standing out in jagged groups, amid bordering tracts of arable or pasture land.

Among other strata grouped as pre-Cambrian are the hard, grey, purple, and brown sandstones, grits and conglomerates, with shales, of the Longmynd, in Shropshire;

and the red sandstones and associated slaty beds of the north-west of Scotland, known as the Torridon Sandstone, which forms much rugged and barren, although picturesque, scenery.

Roofing-slate is obtained in some places; also much hard stone, used for local building-purposes, walls, etc., and for road-metal. Fine-grained siliceous rock is used for honestones (novaculite). Marble is obtained from the limestone on Tiree.

The land occupied by the oldest rocks is not always the most elevated, as in many tracts of Lewisian gneiss.

Some of the steepest, grassy slopes are to be encountered on the Malvern Hills, and on the Longmynd, where there is good pasture.

In the Highlands the deer forests extend over many mountainous areas of the Highland Schists. The valley-bottoms and lower slopes, with alluvium and Drift, are cultivated in many parts.

In the West Highlands certain tracts of grass, with short heather and bracken, are known as 'green lands,' and some of these were formerly under cultivation. The better soils are met with in the limestone areas, and where decomposed igneous rocks, such as epidiorite, etc., occur.

The rocks of western Galway, Mayo, Donegal, and Londonderry include various schists, also brown quartzites with white crusts, rendering them often conspicuous on the mountain slopes. (See Plate I.)

The ponies of Connemara are pastured on the uplands formed by the older rocks before mentioned; and it has been remarked that 'the high temperature, together with the moisture, implies that grasses, heaths, and other plants begin to grow early in the spring, remain fresh and green throughout the summer, and retain their nutritive properties, almost undiminished, during the winter. It is largely for this reason that Connemara has the advantages over the New Forest, Wales, and other pony districts in England.'

The soils in Connemara, with the exception of Boulder Clays, alluvial deposits, and Blown Sands, have been almost entirely derived from the weathering of schists and igneous rocks. These rocks include limestone bands and numerous igneous dykes, and the soil is in general fertile, except in the quartzite mountains.*

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* 'Ireland: Industrial and Agricultural,' 1902, p. 345.

CHAPTER XXV

GEOLOGICAL FORMATIONS (*Concluded*).
6. IGNEOUS ROCKS

THE igneous rocks, from their mode of origin, appear in different forms: (1) In immense more or less lenticular masses known as 'laccolites,' or in irregular bosses; (2) in belts or strips of rock, known as 'sills,' that have been intruded more or less obliquely through sedimentary or other rocks; (3) in narrower and often vertical wall-like masses or dykes; and (4) in great sheets that were poured out as lava, or heaped up as ashes, on the surface of the land or sea-bed in ancient or modern times.

1. Examples of great granite masses are seen in the Scilly Isles, Cornwall and Devon, Lundy Island, Jersey, Shap Fell, Aberdeen, Peterhead, Ben Nevis, Ben Cruachan, the Wicklow and Mourne Mountains, etc.

Various igneous rocks, such as gabbro, syenite, etc., occur in large mountainous masses. Granites, like other igneous rocks, are of various ages, though it is true that some of the most ancient rocks, as already noted, are of granitic nature, being granites that have been subjected to great pressure-metamorphism, so as to have become altered into gneisses. Granite areas are naturally barren at high elevations, but are often fertile in lower lands, where the rocks have become decomposed.

Mr. G. P. Merrill has noted the occurrence of rotted granite to depths of more than 100 feet. (See also p. 157.)

In Jersey the granite is decomposed irregularly to considerable depths, and every patch of soil is cultivated for potatoes, tomatoes, etc.

Elsewhere we find a kind of fine, often reddish-coloured, gravel, termed 'growan' in Cornwall, and formed of quartz and felspar detritus mixed with peaty mould, due to the decay of heather, fern, etc. In the Land's End district potatoes grow well on the dry, friable soil, the land being protected by many stone fences. On Lundy Island, where the loose soil is liable to be blown away in stormy weather, the fairly level top is mostly grass-land, pasture for sheep, cattle, and horses; but wheat, oats, barley, swedes, and turnips, are cultivated. The soil contains a good deal of saline matter from sea-spray.

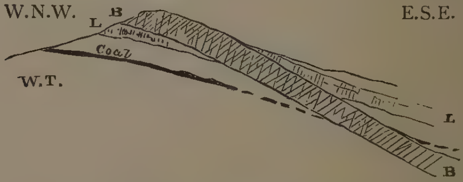

Fig. 44.—Section through Ward's Hill, near Rothbury, Northumberland. (W. Topley.)

B, Whin Sill (Dolerite).
L, Limestone in Carboniferous Limestone Series.

White clay, due to the decomposition of felspar and the formation of hydrous silicate of alumina, is found in places on the Scilly Isles, as well as growan, where potatoes, wheat, barley, grass, and flowers are cultivated.

De la Beche has remarked that the lower elevations near Dartmoor, as at Moreton Hampstead, are the more fertile, and barley, oats, etc., are there grown.

2. Of sills, the most notable example is the Great Whin Sill (Fig. 44), which was intruded along different horizons

among the Lower Carboniferous rocks of Cumberland, Northumberland, and Durham. It yields a good soil where decomposed. Other examples occur in the columnar basalt or dolerite of the Giant's Causeway, Staffa, Skye, etc.

3. Of dykes, countless examples occur in some places, as in the Lower Lias of Broadford in Skye, in Pabba, and in many other formations and areas.

Most of these are formed of dolerite or basalt; in other cases of epidiorite. All are sometimes grouped under the general name of 'greenstones.' By reason of their greater or less hardness, they sometimes stand out in wall-like masses; at other times they have been eroded, so as to leave deep fissures in the rocks. The decomposed greenstones in the Penzance district are regarded as yielding a superior soil for potatoes. Dykes of minette give rise to a fertile soil supporting good herbage, as in Strathglass, in the North-West Highlands. Many elvan dykes traverse the granites and slates of Cornwall, occasionally attaining a width of 150 feet. The rock is used for building-purposes.

4. Sheets of lava and accumulations of ashes occur interstratified among formations of all ages, as in the Borrowdale Volcanic Series (green slates and porphyries), the Derbyshire Toadstone, and in the bedded basalts of Antrim and the Western Isles of Scotland.

Some of the more recent volcanic accumulations and soils have been previously mentioned (p. 115).

The igneous rocks (andesites and porphyrites) in the Lower Old Red Sandstone of the Cheviot Hills, as noted by Mr. C. T. Clough, yield soils that produce short, sweet grass, excellent for sheep-pastures.

The green slates and porphyries of the Borrowdale Series form rough mountain-land; the slates have been quarried at Langdale, Troutbeck, and Kentmere. Associated with these igneous rocks, near Seathwaite, is the Borrowdale black-lead mine, where graphite or plumbago (nearly pure carbon) has been worked for lead-pencils, and has been used for marking sheep.

The Gabbro, of Skye, as remarked by Mr. A. Harker, is decomposed in places into a sand of broken felspar and rusty clay. All the basic igneous rocks are liable to spheroidal weathering along joints, whence arise the rounded masses, with exfoliating crusts. (See Plate II.)

In Skye the intrusive sills of dolerite, with columnar jointing, form the main features or terraces in the large basaltic plateau areas, while the lavas, mostly amygdaloidal, are more readily decomposed. There is evidence also of some intermediate or contemporaneous weathering during pauses in the outflows of basaltic lava, the decomposition resulting in more or less ferruginous clays, and of hardened bands of red clay approaching lithomarge in character. Mr. Harker has observed that, 'unlike many other areas of somewhat similar geological constitution, the basaltic tract of Skye is remarkably sterile. Cultivation of any kind is possible only in some of the broader valleys, where the rocks are covered by a mantle of Boulder Clay. Above the Drift-line soil and subsoil are wanting. Several causes contribute to this result—the intractable nature of the sill rocks, the scouring of the country by ice, the excessive rainfall under existing conditions, and the prevalent covering of peat, which effectively protects the rocks from subaerial decay.' *

The decomposed igneous rocks of South Devon yield some of the most fertile soils, partly downwashed, as noted by De la Beche, who mentions that the material has been worked in 'marl-pits' for manure. Thus land on the

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* 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Survey*, 1904, pp. 29, 123, 438.

vesicular trap-rocks, known as 'dunstone,' is highly esteemed.*

The Serpentine of the Lizard forms moory and marshy tracts, with some wooded valleys, but is generally infertile, compared with the associated rocks.

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